SANDEE

South Asian Network for Development
and Environmental Economics

SANDEE
PO Box 8975 EPC 1056
Kathmandu, Nepal

Tel: 977-1-552 8761
Fax: 977-1-553 6786
E-mail: info@sandeeonline.org
Website: www.sandeeonline.org

SANDEE Sponsors

IUCN

NORAD

Sida
Swedish International Development
Cooperation Agency

IDRC CRDI
International Development Research Centre
Centre de recherches pour le développement international

WORKING PAPER

No. 25-07

Storm Protection by Mangroves in Orissa: An Analysis of the 1999 Super Cyclone

Saudamini Das

SANDEE
South Asian Network for Development
and Environmental Economics

December 2007

Storm Protection by Mangroves in Orissa: An Analysis of the 1999 Super Cyclone

SAUDAMINI DAS

Swami Shradhanand College
University of Delhi, India

December 2007

South Asian Network for Development and Environmental Economics (SANDEE)
PO Box 8975, EPC 1056
Kathmandu, Nepal

SANDEE Working Paper No. 25-07

Published by the South Asian Network for Development and Environmental Economics (SANDEE)
PO Box 8975, EPC 1056 Kathmandu, Nepal.
Telephone: 977-1-552 8761, 552 6391 Fax: 977-1-553 6786

SANDEE research reports are the output of research projects supported by the South Asian Network for Development and Environmental Economics. The reports have been peer reviewed and edited. A summary of the findings of SANDEE reports are also available as SANDEE Policy Briefs.

National Library of Nepal Catalogue Service:

Saudamini Das
Storm Protection by Mangroves in Orissa: An Analysis of the 1999 Super Cyclone
(SANDEE Working Papers, ISSN 1893-1891; 2007- WP 25)

ISBN: **978 - 9937 - 8015 - 5 - 3**

Key words:

1. Mangrove cyclone protection
2. Storm surge
3. Human casualty function
4. House damage
5. Livestock loss
6. Wind velocity

The South Asian Network for Development and Environmental Economics

The South Asian Network for Development and Environmental Economics (SANDEE) is a regional network that brings together analysts from different countries in South Asia to address environment-development problems. SANDEE's activities include research support, training, and information dissemination. SANDEE is supported by contributions from international donors and its members. Please see **www.sandeeonline.org** for further information about SANDEE.

SANDEE is financially supported by International Development Research Centre (IDRC), Swedish International Development Cooperation Agency (SIDA) and Norwegian Agency for Development Cooperation (NORAD).

Technical Editor
Pranab Mukhopadhyay

English Editor
Rahul Goswami

Comments should be sent to Saudamini Das, Swami Shradhanand College, University of Delhi, India. Email: sdas_28@yahoo.com.in

TABLE OF CONTENTS

LIST OF TABLES

LIST OF APPENDIX

LIST OF FIGURES

Abstract

This study assesses the storm protection role afforded by mangroves. It uses data on human casualties, damages to houses and livestock losses suffered in the Kendrapada district of the State of Orissa during the super cyclone of October 1999. The cyclone (of T 7 category) devastated 12 of the 30 districts of Orissa causing 9,893 human casualties and 441,531 livestock deaths, and damaging 1,958,351 houses and 1,843,047 hectares of crop.

The analysis incorporates meteorological, geo-physical and socio-economic factors to separate out the impact of mangrove vegetation on cyclone damage. The results indicate that the mangroves significantly reduced human death and seemed more effective in saving lives (both human as well as animals) than in reducing damage to static property. While there was significant reduction due to mangroves in damage to residential houses and to big animals like cattle and buffaloes, these results were not robust.

If the width of the mangrove forest was 10% more that what it was at the time of the cyclone, human casualties would have been lower by 12.48 %, buffalo loss by 6.6 %, cattle loss by 2.23 % and fully collapsed houses by 2.21%. Factors like land elevation, immovable asset holdings, etc., too, had decisive effects on human casualties in the storm surge affected areas.

Key words: Mangrove cyclone protection, storm surge, human casualty function, house damage, livestock loss, wind velocity

Storm Protection by Mangroves in Orissa: An Analysis of the 1999 Super Cyclone

Saudamini Das

1. Introduction

Tropical cyclones cause widespread damage to environment and property and lead to high human casualties in coastal areas. The impact however varies depending on factors like the intensity of the cyclone, the nature of the topography (elevation, drainage), etc. Coastal forests play an important protective role against cyclone-generated wave and wind attacks. In order to arrive at an exact estimate of the protective role played by coastal forests, all factors that influence the impact of cyclones should be simultaneously considered so that the exact contribution of each factor when it comes to the impact can be accurately determined.

Mangrove ecosystems provide many direct and indirect benefits to humankind (Dixon, 1994) but most of the indirect benefits are under-researched. Research on climate change however suggests that there would be an increase in the frequency and intensity of cyclones (Steffen, 2006). In this context, it is very important to understand the storm protection that mangroves provide.

Although theory suggests that mangroves reduce cyclone impact by dissipating wave energy, the empirical studies have not established this satisfactorily (Massel, et al., 1999; Mazda, et. al., 1997 and 2006; Fosberg, 1971; Badola & Hussain, 2005; Quartel, et. al., 2007; Harda and Imamura, 2005; Khazai, et. al., 2007; Kerr and Baird, 2007; Chatenous and Peduzzi, 2007; Cochard, et. al., 2008).

We investigate this issue in relation to the mangrove forests of Orissa, a state in the eastern part of India, using data on damage suffered during the super cyclone of October 1999. This cyclone was a T-7 category[1] cyclone with a landfall wind velocity of 256 kmh^{-1} and was stationary at different locations in the state for a number of hours for over three days (IMD, 2000; Gupta & Sharma, 2000). It devastated 12 of the 30 districts of Orissa causing 9,893 human casualties and 441,531 livestock deaths, and damaging 1,958,351 houses and 1,843,047 hectares of cropland (Gupta and Sharma, 2000). Moreover, mangrove areas of Orissa (Kendrapada district) are the most cyclone prone area of Indian peninsula (Das, 2007). Storm protection by mangroves, if found significant in protecting life and property, will be the most important ecosystem service of mangroves to the state.

This study analyzes every possible factor that influenced the degree of cyclone damage and offered storm protection to human life, livestock and residential houses. In section 2 of the study we briefly review the relevant literature. Section 3 introduces the study area; section 4 describes

---

[1] Cyclonic disturbances are categorized and given different T Nos depending on their damage potential and landfall wind velocities. Cyclone types like Deep Depression (T=2.0, wind speed= 50-61kmh^{-1}), Cyclonic Storm (T=2.5 to 3.0, wind speed=61-88 kmh^{-1}), Severe Cyclonic Storm (T= 3.5, wind speed=88-117 kmh^{-1}) cause minor to moderate damages, whereas cyclone types like Very Severe Cyclonic Storm (T=5.0 to 6.0, wind speed=117-220 kmh^{-1}) and Super Cyclone (T=6.5 and above, wind speed > 221 kmh^{-1}) cause catastrophic damages.

the data used; section 5 gives the methodology; section 6 provides the estimated results and discussion while Section 7 concludes with some policy recommendations.

2. Literature Review

The early models that examined the storm protection services offered by wetlands used wind velocity as a determining factor (Farber, 1987). However, this analysis had two limitations: firstly, the assumption of the homogeneity of population, which ignores the role of socio-economic factors on the severity of damage and, secondly wetlands reduce wind damage only if they have high vegetation.

The study that was undertaken by Badola and Hussain (2005) in the aftermath of the super cyclone of October 1999 has specification errors some of which may over-estimate the protection services of mangroves. The study villages are again assumed to be socio-economically homogeneous when they are not. Moreover, it does not consider the hydrology drainage characteristics, such as the distance from rivers, the position of dikes, etc., vis-à-vis rivers and the villages. In the case of some villages, the researchers credited to mangroves part of the protection that may have come from the dikes. Further, the study villages were not equi-distant from the cyclone path and therefore would have experienced a different wind impact.

Literature on extreme events (cyclones, tsunami etc.) analysis on the other hand have considered elevation, coastal distance and inundation distances as the other critical factors impacting damages (Bretschneider and Wybro, 1977; FAO, 2006; Baird, 2006; Chatenoux and Peduzzi, 2006, 2007; Cochard, R., et al., 2008; Dahdouh-Guebas, et. al., 2006). However, the literature does not discuss the role of economic, sociological and hydrological factors and the characteristics of mangrove habitat areas, particularly in the context of developing countries.

This paper addresses these gaps in its evaluation of the protective role of mangrove forests. The study is more comprehensive because it also takes into account socio-economic and environmental factors and meteorological variables such as sea-level elevation (storm surge height) and radial wind. The present study also aims to control for mangrove habitat characteristics not observed in previous studies in order to isolate the mangrove vegetation effect by (1) including the width of the mangrove habitat areas between a village and the coast and (2) by studying only those villages that historically had mangroves separating them from the coast. The second aspect also controls for the bathymetric and topographic features of the study area. We define the mangrove variable in the present paper as the width of the forest (not the area) between the village and the coast as the spread of the forest along the coast is continuous and the width of the forest is different at different places.[2] Thus, the partial storm protection estimates are for the kilometer width of the forest although we also provide the approximate per hectare estimates.

3. Study Area

We analyze three different types of damage, mainly in the Kendrapada district of Orissa State (see Figure 1). We have extended the study area beyond Kendrapada in a northeasterly direction in order to study human casualties and in a southeasterly direction to study house damage.

[2] The "length" of the forest is its spread in kilometers (km) parallel to the coast and its width is the spread inland (vertical to the coast) measured in km.

3.1 Kendrapada District

Orissa is one of the most backward states of India with 48 percent of the population living below the poverty line. The district of Kendrapada ranks 10 among the 30 districts of the state in terms of the Human Development Index (HDR, 2004). It is a predominantly agricultural district with 78 percent of the population dependent on the primary sector and just 5 percent on the secondary sector. More than 50 percent of the population in all the tahasils[3] (except Kendrapada tahasil) live below the poverty line (see Appendix Table 12). During the super cyclone, human casualties were witnessed in all tahasils, except Rajkanika, the maximum (188) being from Mahakalpada (closer to the cyclone landfall) and the second highest (67) from Derabis, the block with the highest population density (740) and the highest percentage of people below the poverty line (67%). The absence of human deaths from Rajkanika which lies on the leeward side of the mangrove forests of Rajnagar tahasil suggests a link between mangroves and the protection that they may afford.

In Kendrapara district, coastal mangrove forests are present only in the Mahakalpada and Rajnagar tahasils (see Figure 2) where eighty percent of the 60 km long coastline was covered with mangrove forests. The 1950 map of the area indicates that the mangrove forests were nearly 10 km wide then (see Figure 3). In 1952, the ownership of these forests was transferred from the Zamindars (feudal land owners) to the state government. In 1980, the state government established the Wild Life Division and the management of the mangrove forests came under the exclusive jurisdiction of this division (GoO 2004, ODG 1996).

By 1999, the Mahakalpada tahasil had witnessed large scale land use change leaving only a thin strip (width less than 1 kilometer) of mangroves. In contrast, the mangroves in Rajnagar tahasil have been well preserved (see Figures 2 and 3). This forest area was declared the Bhitarkanika Wildlife Sanctuary in 1975 and a national park by 1988. The Mahakalpada forests, though declared a reserve forest in 1978, were brought under the Gahirmatha Marine Wildlife Sanctuary only in 1997. The district has 192 sq. kms of mangrove forests as per the 2001 survey, more than 93 percent of it being dense and well-protected (FSI, 2001).
We give below the reasons for selecting Kendrapada for this study:

(i) The super cyclone had its landfall 20km southwest of Kendrapada, and the entire district experienced severe cyclonic winds and rain. Storm surge affected four of the eight tahasils .
(ii) The wind direction in this district was mainly from sea to land during the super cyclone.[4] Since the wind was reaching the interior after crossing the mangrove forests, it offered a good opportunity to test the wind buffering capacity of the mangroves.
(iii) The entire district is devoid of highlands. The elevation in the district is less than 10m and, in coastal blocks, less than 4m. The only wind and storm surge barriers are the forests, the sand dunes and the saltwater dikes in the coastal areas.
(iv) The only forests in the district are the mangrove forests in the coastal areas.[5]
(v) The district has coastal areas with mangroves as well as areas with barren coastline

---

[3] Tahasils are local administrative units under a district.

[4] In the northern hemisphere, the direction of cyclonic winds is anti-clockwise. The district lay to the north of the cyclone landfall and the cyclone eye.

[5] The main forests were the mangroves though a few patches of casuarinas plantations were also to be found in the coastal areas before the cyclone. But the width of these plantations everywhere was between 200 to 400 meters.

while the width of the mangrove forests varies from 100 meters to 10 kilometers at different places (see Figure 2). These features provided scope to compare the cyclone impact when mangroves were absent and also to compare its impact on the different widths of the mangrove belt.

3.2 The Super Cyclone Of 1999

The 1999 Super cyclone was extremely slow, moving with an average speed of 22 to 25 kmh^{-1}. It moved northwest after landfall and then lay centered over the Garadpur tahasil of Kendrapada for three hours. This was the centroid of a triangle formed by Kendrapada, Paradeep and Jagatsinghpur towns of Orissa. The cyclone then moved in a southwesterly direction away from Kendrapada district and lay centered near Bhubaneswar, the state capital, for nearly 35 hours (IMD, 2000; Gupta and Sharma, 2000). Hence, the district received maximum damage due to the cyclone when it was making landfall and when it remained stationary over Garadpur.

4. Data

We used five different categories of secondary data such as damages due to the super cyclone, meteorological information, environmental information, socio-economic information and livestock data for the analysis (see Appendix Table 13 for details).

Arcview 3.1 software was used to combine digitized topography, the river network, the road network, and coastal forests (as it existed on 11th October, 1999).[6] The cyclone eye track was thereafter superimposed on the village map for the area and the section over Garadpur (as described above) was used to calculate the radial wind and other distance variables for different villages. The approximate sea elevation at different coastal points was calculated from the surge envelope curve provided by the cyclone warning division of the meteorology department of the Government of India (see Figure 4).

We obtained the socio-economic variables from the primary census abstract of Orissa. We extrapolated the 1991- 2001 decadal (compound) growth rate for different variables (population, scheduled castes, different types of workers, etc.) to get the 1999 values. Livestock data was collected from the unpublished documents of the Chief District Veterinary Officer’s office in Kendrapada for the year 2000. In order to compute the 1999 pre-cyclone numbers, we added the lost cattle figures to the 2000 data as the survey for the 2000 livestock census had been undertaken immediately after the super cyclone.

5. Methods

We examine damages of three kinds: to human life, to livestock and to houses (that is, as fully collapsed, partially damaged and swept away houses). Damages would depend on the velocity of wind and storm surge water, the characteristics of the population or property at risk, and other

[6] Indian Remote Sensing Satellite IRS 1D, LISS III pan data of 11th Oct 1999 with 23.9 meter resolution has been used for the 1999 forest cover and for 1950 forest cover, the images were procured from the archives of US Army Corps. Geo-referencing of the images has been done at the 1:50,000 scale.

socio-economic factors of the location.[7] The Damage function is characterized by equation 1:

$$D_i = d\,(V_i, W_i, P_i, S_i) \quad (1)$$

where *i* represents location,

D = damage suffered,[8]
V = wind velocity,
W = velocity of storm surge or the severity of flooding due to surge,
P is population or property at risk,
S is the group of socio-economic and institutional factors.

We will next describe the variables and their estimating techniques used in this paper. Description of all variables used in the equations is provided in Table 1.

5.1 Wind Velocity

The actual wind velocity at a place would depend on the potential radial wind (wind velocity in the absence of any barriers—RWi)[9] and wind barriers (Barriers).

$$V_i = v\,(RW_i, Barriers_i) \quad (2)$$

The radial wind at any location will depend on the horizontal structure of the cyclone which consists of four parts – the eye, the eye-wall or the wall cloud region, the rain/spiral bands, and the outer storm area (IMD, 2002). Sites under the eye and eye-wall receive the maximum wind and the wind velocity over other structures is linked non-linearly with the maximum wind.

The maximum wind of cyclones decreases exponentially after land fall due to interaction with rough surface, reduced moisture supply, conversion of heat in the form of rain, etc. (Dube, et. al., 1981; Basu and Ghose, 1987; Kalpana and Demaria, 1995; Kalsi, et. al., 2003; Singh and Bandyopadhyay, 2005). The maximum wind of the super cyclone declined at an exponential rate of 0.0991 per hour on average (Kalsi, et. al., 2003).

We calculated the wind profile at different radial distances beyond the cyclone's eye using two different specifications: (i) exponential—velocityexp (Ghose, 1977, 1995; Holland, 1980; Dube, et. al., 1981; Basu and Ghose, 1987); and (ii) power function—velocitypow (Depperman, 1947; Jalesnianski, 1965; Das, et. al., 1974; Roy Abraham, et. al., 1995). Specifically,

(i) $Velocityexp_i = V_{max} * \exp(-(dcypath_i - R)/b))$, and
(ii) $Velocitypow_i = V_{max} * (dcypath_i/R)^{-a}$ . . . . (3)

---

7 Rain-related flooding as a cause of damage has been ignored here for the following reasons: lack of spatial difference in rainfall in the study area, unavailability of village specific rainfall data and inclusion in the model of other factors (like distance from coast and cyclone path) which would implicitly control for rainfall.

8 Except D and P, we had no measure of the other variables at the village level and, thus, they are approximated by including their determinants in the damage equation.

9 Radial wind is wind velocity at different horizontal distances from the center of the eye of the storm (cyclone path in the present case) and is dependant on the maximum wind at the cyclone eye wall.

The maximum wind (V_{max}) for Garadpur[10] was calculated as:

V_{max} = 256 kmh^{-1} exp. (- 0.0991 * 3) = 190.1622 kmh^{-1} . . . .(4)

$$\text{Radial Wind } (RW_i) = \begin{cases} \text{Vmax } (=190.1622 \text{ kmh}^{-1} \text{ if dcypath}_i \leq 15 \\ \text{Velocitypow (or exp.) if dcypath}_i > 15 \end{cases} \quad \ldots\ldots(5)$$

The wind barriers were the mangrove forests (width ranging from 0.1 to 10 km), the casuarinas forests (width ranging from 0.2 to 0.4 km) on the coastline and the distance of a village from the coast (dcoast).

$$\text{Barriers}_i = B\,(\text{mangrove}_i, \text{mhabitat}_i, \text{casuarinadumy}, \text{dcoast}_i) \ldots\ldots(6)$$

As the casuarina forests were almost uniform in width (wherever they were present), it was represented by a dummy variable. Mhabitat (the width of the mangrove habitat area) is used here to control for any unobserved surface roughness factors of the mangrove habitat area that may have some impact on wind velocity.

Substituting equation (5) and (6) into equation (2), the actual wind velocity at the i^{th} village is derived as[11]:

$$V_i = v\,[V_{max} \text{ (if dcypath}_i \text{ £ } 15), \text{velocitypow or velocityexp (if dcypath}_i > 15), \text{dcoast}_i, \text{ mangrove}_i, \text{mhabitat}_i, \text{casuarinadumy}] \ldots\ldots(7)$$

5.2 Velocity of Storm Surge

In addition to wind velocity, we also need to include sea elevation (surge) in order to explain cyclone damage.[12] Storm surge is an abnormal rise in sea level in excess of the predicted astronomical tide and is caused mainly by the atmospheric pressure variation and the strong surface wind of a cyclone.[13] Severity of flooding depends on the level of sea elevation (surge) and other physical features of the location like distance from the coast, elevation, topography and hydrology of the place, distance from river channels, presence of natural barriers like mangroves, sand dunes or any other natural or man-made barriers (dikes) near the village, etc. We defined the following function to explain the severity (or velocity) of flooding due to storm surge:

---

[10] The wind velocity at landfall was 256 km per hour. The cyclone took nearly 3 hours to reach Garadpur (2 hours for landfall and 1 hour to cover the distance between landfall and Garadpur). The radius of the cyclone eye was reported to be approximately 15 km. We assume a to be 0.6 and b to be 240 km after consultations with meteorological experts.

[11] We approximated wind velocity by including the five variables of eq-7 in the main model since the actual values were not available. The variables "dcoast" and "mangrove" also implicitly control for the distance of village from the mangrove forest.

[12] In the October 1999 cyclone, only a 40 km stretch experienced a very high surge, even though nearly 250 km of the coastline was battered by very high surface winds (see Figure 4).

[13] Along with wind velocity and pressure variation, other factors that play a decisive role in the generation of the storm surge are the direction (inclination) of the cyclone at landfall, radius of maximum wind, local offshore bathymetry, inland topography, density of sea water, speed of the cyclone, the height of astronomical tide, etc. (Kalsi, et. al, 2004). Therefore, there is no one-to-one relation between wind velocity and sea elevation.

$$W_i = w\,(surge_i, dcoast_i, dmajriver_i, dminriver_i, topodumy_i, mhabitat_i, mangrove_i, casurinadumy, roadumy) \qquad (8)$$

The study area is full of major and minor river channels and their behavior during storm surge are different. The major rivers carry away the high velocity surge water to interior areas and, as a result, nearby villages may experience reduced flooding. However, the opposite happens in the case of minor rivers. To distinguish between minor and major rivers, we use two different distance variables—dmajriver and dminriver.

In the absence of elevation data for all the villages, we used present and historical (as existed in 1950) mangrove forest maps to demarcate the low-lying areas (see Figures 2 and 3). As mangrove forests come up in low lying vulnerable areas that get inundated regularly during high tides, we assume topodummy = 1 for villages that are low lying, i.e., they had mangrove vegetation within its boundary historically or in 1999 while we assume topodumy = 0 for those villages situated at higher elevation levels.

$Mhabitat_i$ is the width of the historical mangrove forests that lay between the village and the coast as seen in the 1950 forest map (see Figure 3). This variable is likely to capture the effect of the topographic, hydrological and bathymetric factors of the mangrove habitat areas in storm surge inundation. The study area had a vast stretch of mangrove forests historically and there have been large scale land use change over the years. We expect the physical features of mangrove areas to be different and for its width to capture its impact on cyclone damage. Moreover, we thought this variable would control for any unobserved confounding factors that could cause a spurious correlation between the mangroves (present before the 1999 cyclone) and the damages.

The entire coastline of the study area was planted with casuarinas trees after a severe cyclone in 1972. Casuarinas grow on sandy beaches and on sand dunes that are more elevated than the areas where mangroves grow and do not get inundated during high tides. Since this area is mostly swampy and low-lying, casuarinas could survive only in some limited pockets and are of near uniform width (0.2 to 0.4 km). Hence, we use the casuarina dummy to capture the effect of casuarina vegetation as well as the special topography of the casuarina forest area.

Roadumy, the dummy variable for the presence of village road, captures the effect of the dikes (which substitute as village roads along the coast).

5.3 Socio-Economic Factors

We expect the cyclone, like any other natural calamity, to have a differential impact on people depending on their socio-economic status. We assume the coastal poor to be the most vulnerable during cyclones (FAO, 2000).[14]

[14] A wealthy household would have a good quality house, vehicle to evacuate in emergency, radio or television to receive cyclone warning and being better educated would most likely react quickly to cyclone warnings. In contrast, a poor household has low quality houses, located in low-lying vulnerable areas, have low levels of education and fewer sources of information. Even if informed, they are unlikely to find any means to evacuate. Their lower health status would also affect their ability to survive illness or any epidemic in the aftermath of a natural disaster.

In addition, the institutional and infrastructural as well as behavioral factors would also play decisive roles in averting damage during cyclones. Efficiency of the meteorology department in providing accurate cyclone warnings, promptness of the local administration (tahasildar in the present case) in the proper dissemination of the cyclone warning or evacuating people from vulnerable areas, the presence of cyclone shelters or some other concrete structures in neighborhoods, community orientation of people in helping each other during a crisis, etc., also play important roles.

In the absence of a proper economic well-being index for the villages, we capture the differences in socio-economic conditions by using factors like percentage of literates (FAO, 2000), percentage of different types of workers, percentage of scheduled caste population (economically and socially most deprived), percentage of non-workers (who are likely to remain indoors and hence less exposed during cyclones), the proximity of villages to a metalled road, presence of village road, dummies for local administration, etc.[15] Thus the socio-economic well-being index impacting on the cyclone damages is:

S_i = S (tahasildar, literate, scheduledcaste, cultivators, aglabours, hhworkers,
otworkers, margworkers, nonworkers, droad, roadumy). . . . .(9)

Combining the factors affecting wind velocity, surge velocity, population (or property) at risk and socio-economic conditions, we obtain the following cyclone damage function for a village[16]:

D_i = d (tahasildar, V_{max} or velocitypow (or velocityexp), surge, dcoast,
topodumy, mhabitat, mangrove, casurinadumy, dmajriver,
dminriver, droad, roadumy, population99, literate,
scheduledcaste, cultivator, aglabour, hhworkers, otworkers,
margworkers, nonworkers). . . . . (10)

6. Results and Discussions

This study attempts to evaluate the sheltering capacity of the mangrove forest against the destructive effect of the cyclone. We have excluded areas that never had mangroves in the coast-village interface (mhabitat = 0) for reasons already explained in Section 2 and also areas coming under the cyclone's eye.[17] As this sample was to provide a more accurate picture of the protective services of the mangrove vegetation, we further subdivided the sample to evaluate the effectiveness of mangrove protection for areas that are located at different distances from the coastline and for areas affected by the storm surge. Thus, we estimated regressions for five different samples as described below (and Mhabitat > 0 for all samples).
Sample 1: Whole sample

[15] In the absence of data on access to mass media (TV, radio) at the village level, we take the percentage of other workers (otworkers) that include people with high education, high mobility and in occupations other than agriculture and household industries (doctors, teachers, engineers, barbers, washerman, priests, etc.) as proxies for availability of this commodity.

[16] We have ignored factors like time and season of occurrence of the cyclone, number of hours of advanced warnings to cyclone, etc., as the analysis is for the damage data of a single cyclone.

[17] Wind direction inside the cyclone's eye is circular, and no forest can provide any sheltering service against wind effects.

Sample 2: wind velocity < 190 km per hour[18]
Sample 3: wind velocity < 190 kmh^{-1} and Dcoast <= 10
Sample 4: wind velocity < 190 kmh^{-1} and Dcoast > 10
Sample 5: Storm Surge affected areas and wind velocity < 190 kmh^{-1}

Wind velocity and storm surge are the two main causes of cyclone-related damage. We tried to use the most appropriate measure of these variables.[19]

Table 2 presents the summary statistics of the three damage functions for sample 1. The average values of most variables are similar to each other for the three different models. The minimum and maximum values of "dcypath" and "dcoast" show that the villages that suffered human casualties lie within 0.34 to 51.23 km from the coastline, and 0.62 and 83 km from the cyclone path. On the other hand, the villages that suffered house damage lie within 0.65 to 51.23 km from the coastline and 0.22 to 72.83 km from the cyclone path while livestock loss is from areas lying within 2.19 to 49.33 km from coast and 0.62 and 72.83 km from the cyclone path

We estimated the damage function (equation 10) for the three types of damage starting with human casualties. Different estimates were used depending on the nature of the damage data (see Table 3).[20]

6.1 Human Casualties (HC)

This model is estimated using village level data for the 1095 revenue villages of Kendrapada district and 85 coastal villages of the nearby Chandbali tahasil of Bhadrakh district that are located next to the mangrove forest in a northeasterly direction.[21] This model includes areas falling under nine tahasildars (from Mahakalpada to Bhadrakh) which are represented by dummy variables with the respective tahasil names.

The dependant variable, "sucydeath", is a count as most of the observations are either 0 or 1. Hence a Poisson distribution is used for this model. The Poisson regression model assumes each y_i to be drawn from a Poisson distribution with parameter l_i (the conditional mean of the variable) which is assumed to be related to the regressors X_i. The primary equations of the model are:

---

[18] Estimated V_{max} is 190.1622 km h^{-1} (see equation-4).

[19] We have used two different measures of wind velocity–one given by a power function (velocitypow) and the other by an exponential function (velocityexp) as explained in equation 3. We estimated every damage function twice.
Our estimation was done using the direct measure of sea elevation (surge) as an independent variable. We estimated three alternative crude measures of flooding due to storm surge:
Flooding 1 = Surge * exp (- dcoast),
Flooding 2 = surge/dcoast, and
Flooding 3 = surge + a dcoast – b $(dcoast)^2$
The last 2 measures gave unacceptable results. Estimates of flooding 1 in place of surge gave both better results as well as expected signs of the coefficients, but only for those damages caused mainly due to storm surge. Some of these results are discussed in the text and are shown in the appendix.

[20] It presents the heteroskedasticity test results for sample 1 only.

[21] Though Chandbali tahasil was included in the human death model, we could not include it in the house damage or in livestock loss models as the data on house damage or livestock loss was not available to us.

$$P(y_i = y_i) = \frac{e^{-\lambda_i}\lambda_i^{y_i}}{y_i!}, \quad y_i = 0,1,2, \quad \ldots \qquad (11)$$

and $$\lambda_i = exp(\beta_0 + \beta_1 x_1 + \beta_2 x_2 + ---) \ldots \qquad (12)$$

In the present case, the estimating equation is E(sucydeath) =

$$\lambda_i = \exp(\beta_0 + \beta_1 Tahasildar_i + \beta_2 wind\ velocity_i + \beta_3 surge_i \ldots \qquad (13)$$
$$+ --- + \beta_{29} nonworkers + \varepsilon_i)$$

where e_i is the error term.

We show the Poisson estimates for different sample areas in Table 4. The regression based over-dispersion test (Greene 2000) for sample 1 found the a coefficient to be insignificant. To reconfirm these results we also used the negative binomial (NB) estimates (Table 5).[22] The Chi square statistics for LR test of alpha = 0 as shown in Table 5 supports the negative binomial estimates for all sample areas except sample-3 even though the over-dispersion test suggested the use of the Poisson model.[23] However, we have analyzed the Poisson results and have used this model for calculating averted deaths later on as these results, we felt, reflected the reality better.[24] We rejected both Zero-Inflated Poisson (ZIP) and Zero-Inflated negative binomial (ZINB) distributions for all the sample areas on the basis of the Vuong test.[25] We also estimated these models both with and without tahasildar dummies and found mangrove to be significant under both the specifications.[26] In both table 4 and 5, we use the "velocitypow" measure of radial wind.[27] Interestingly, we found the mangrove variable significant for all sample areas irrespective of the type of estimates or the model specification used (including ZIP and ZINB).

Expected Signs & Discussion

We expect the tahasildar dummies to be proxy for the institutional arrangements of the local administration that play very important roles during natural calamities when it comes to saving human lives as well as other movable properties. Accurate and timely forecasting of the cyclone, proper dissemination of cyclone warning, evacuating people from vulnerable areas, providing

22 Poisson distribution has a nice robustness property: whether or not Poisson distribution holds, we get consistent and asymptotically Norman estimates of b_i (Woolridge, 2000, pp-584)

23 Negative binomial distribution can control for the over dispersion problem by scaling the standard errors (Greene, 2000, pp-884).

24 However, the averted deaths (by mangrove) estimated in the negative binomial model are higher than those of Poisson model. To that extent, the Poisson model under-estimates the impact of mangroves.

25 Zero-inflated Poisson (ZIP) and zero-inflated negative binomial (ZINB) estimates were also tried for this model as nearly 80 % of the observations of the dependent variable, sucydeath, were of zero value. Vuong test statistic for the acceptance of the null hypothesis of preferring ZIP to standard Poisson for different sample areas follows: (sample-1: z=1.10, P=0.13; sample=2: z=1.18, P=0.12; sample-3: z=0.23, P=0.41; sample-4, conversion not achieved; sample-5: z=1.31, P=0.95) and the corresponding values for the null of zinb verses nb were (z=0.57, P=0.29; z=0.01, P=0.49; z= missing; z=0.72, P=0.23; z=0.07, P=0.47).

26 The models without the tahasildar dummies are unreliable, particularly in the case of human casualties, due to the omitted variable of governmental institutions and therefore we do not show them.

27 The mean and standard deviation of the two measures of wind velocity (velocitypow and velocityexp) was very different (Table 2) but we found the coefficient of correlation between them to be very high (around 0.97 for different samples). So we expect the results with both the measures of wind to be similar. For purposes of comparison, we present the Poisson coefficients using the alternative measure of wind velocity (velocityexp) in Appendix Table 14.

logistics (particularly in a poor and backward region) and basic facilities, making post-cyclone arrangements for return and rehabilitation, etc., crucially affect human survival. The tahasildars play an important role in this context. We also expect these dummies to capture the effects of any other omitted variables specific to the administrative unit. However, we do not know the characteristics of the local administration a priori. Similarly, we also do not know how the width of the historical mangrove forest (Mhabitat) or the physical features of mangrove habitat areas would affect human death?

We expect the coefficients of topodummy, wind velocity and surge to be positive as the high values of these variables indicate greater human casualty. We also expect positive coefficients for dmajriver (major rivers carry away the surge water, hence death toll near the river is lower), droad (because of the higher economic status of people near the roads, damage is lower), pop99, scheduled caste, aglabour and margworkers (the last three belong to the economically weaker sections who are therefore more vulnerable). In contrast, we expect negative coefficients for dcoast (less distance from coast means more human deaths), mangrove (greater vegetation is expected to provide protection), dminriver (areas nearer to small rivers experienced more severe flooding as small rivers have low capacity to absorb water and, hence, less distance means more deaths), roadumy (high value indicates that the presence of village road means more prosperity and hence less death), literate (educated people respond more quickly), cultivator, hhworker and otworkers (all three categories are economically well-off compared to other groups in the study area) and, finally, non-workers (who are likely to stay indoors and are hence less exposed during cyclones).

In all the different variations of the estimated damage function, the mangrove variable is significant with a negative sign. This strongly suggests that mangroves significantly reduced human casualties. This result is robust to changes in sample size, sample type, wind velocity measures or the type of institutional setting.

Interestingly, other coastal forests, particularly the casuarinas, do not seem to be effective against cyclones. In the damage function, casuarina dummies, wherever significant, have a positive sign (as opposed to the mangrove coefficient).[28] Witnesses recall that casuarina trees broke down with the first gusts of cyclonic wind. We discuss the regression results by grouping the various factors into 4 categories – geo-physical, institutional, meteorological, and social-economic factors (see mainly Table 4).

(a) Geo-physical factors

Dcoast, Topodummy, Mhabitat, mangrove, casurinadummy, dmajriver and dminriver are the factors considered under this category. Except for dcoast, the rest of the regressors are significant either in some or all equations. We concentrate on the analysis of three variables capturing different aspects of the mangrove habitat areas on human deaths. Topodumy, which identifies villages that are located in areas where mangroves are currently present or where they existed in the historical past, captures the vulnerability of these areas due to low elevation. The Mhabitat captures the effect of the topographic, hydrologic, and bathymetric or any other unobserved confounding factors present and mangrove captures the effect of the current vegetation. Of these

[28] Casuarinas trees grow on sandy beaches that do not get inundated during high tide and hence the terrain of casuarina habitat areas is comparatively more elevated than the mangrove habitat areas.

three factors, both topodumy and Mhabitat seem to have increased the number of human casualty in most of the sample areas.[29]

Mangrove vegetation however seems to be playing a protective role.[30] The marginal effect of the mangrove is negative for every area but its effect dominates over the effects of topodumy and Mhabitat for large areas, i.e., sample 1, sample 2 and sample 4. However, the effect of topodumy (low elevation) is so strong for areas within 10 km from the coast (sample 3) and for storm surge areas (sample 5) that it dominates over the negative effects of both mangrove and Mhabitat indicating the incapability of mangrove vegetation to provide full protection to human life in these areas. The implication is that despite the presence of mangroves, these areas would need evacuation before a cyclone.

Of the other variables in this category, the distance from a major river is significant with a positive sign (only for large samples) and this validates our hypothesis. The distance from a small river is also significant with negative sign.

(b) Institutional Factors

The impact of institutions is expected to be picked up by the tahasildar dummies. However, the tahasils, being small administrative units under a single district, differences in administrative efficiency may not be significant and these dummies capture the local geo-physical characteristics. We found that wherever these dummies are significant, they have a positive sign.

(c) Meteorological Factors

The two meteorological factors in this model are wind velocity and surge. Both are significant in most of the equations but only in the presence of tahasildar dummies. The negative coefficient of wind velocity is probably due to the high correlation between some of the tahasildar dummies, surge and the wind velocity. When the regressions are run without the tahsildar dummies, the coefficient of wind velocity is positive. Storm surge, as expected, seems to have caused more deaths.

(d) Socio-economic Factors

We consider the variables, droad, roadumy, pop99, literate, scheduled caste, different types of workers and non-workers under this category, and most of them conform to the expected signs.

---

[29] However, in sample 4, topodumy is significant with a negative sign as sample 4 is beyond 10 km from the coast and there will be very few observations with topodomy = 1. Most of the villages witnessing deaths are with topodumy =0. In sample 3, Mhabitat is significant with a negative sign indicating the presence of some physical features of mangrove habitat areas, other than the mangrove vegetation, that provide protection to human life in near coast areas.

[30] The marginal effects of the three variables (based on Table 4) are produced in Table 6. The marginal effect of a variable in a Poisson regression model is given by the estimated coefficient of the variable multiplied by the predicted value of the model ($\hat{\beta} \bullet \hat{\lambda}$). However in the case of dummy variables, the marginal effects are given by $\hat{\lambda} * \{\exp(\hat{\beta}) - 1\} = \hat{\lambda} * g$, where g is approximately equal to the bracketed term only if $\hat{\beta}$ has a value less than 1 (Halversen and Palmquist, 1980). Thus for sample 3, the coefficient of topodumy being 2.265051, its marginal effect will be larger than that reported in Table 6, though for other sample areas, it will be nearly the same.

Of the two road variables, the presence of village road (roadumy) has reduced human death (significant with negative sign, particularly in the storm surge areas) as we hypothesized. This could be due to two reasons: households near the roads are economically better off. Also easy access to road might have helped people to evacuate quickly. In contrast, droad (distance from paved road) is significant with a negative sign (indicating more deaths near the state highway), but only over a large sample covering the entire district. This could be due to the coincidence that most of the paved roads were lying very close to the cyclone's eye. Pop99 is significant with positive sign as we expected. Variables like literate, cultivators, aglabour, otworkers, margworkers and non-workers, wherever significant, have the expected signs.

The results on scheduled caste and hhworkers are surprising. The scheduled caste people are socially and economically the most deprived. We expected the percentage of scheduled caste population to have a positive coefficient. In contrast, it is significant with a negative coefficient in 18 of the 25 equations[31]. This seems to negate the hypothesis that economic backwardness causes more deaths during natural calamities. However, this result needs to be carefully interpreted. The study area is economically very backward[32] and theft from unguarded houses is quite common.[33] The scheduled caste households have few non-removable assets, and therefore would be able to leave their houses and reach safer places on hearing the cyclone warning more quickly in order to avoid death. People with household industries (hhworkers) were probably reluctant to evacuate.[34] This could be the reason why the coefficients of hhworkers were positive in all equations and significant for the areas affected by storm surge. These results also negate our expectation regarding the lower vulnerability of rich people. Cultivators, other workers and people with household industries are considered comparatively rich. The first two categories had coefficients which had negative signs (wherever significant) but hhworkers did not. Interestingly, this result was valid only for the storm surge affected areas. One possibility is that hhworkers who have their entire livelihood at home were reluctant to evacuate. Cultivators and other workers may have been less hesitant to evacuate.

6.2 House Damage

The second model that we estimate is the House Damage Function. The study area, as mentioned earlier, has a high level of poverty[35]. Nearly 94 percent of the households in the district live in rural areas and only 2 percent of the households have both concrete roof and as well as concrete walls[36].

---

[31] As most of the scheduled caste people work as agricultural labor, this result could be due to the high correlation between the two. However, the correlation coefficient between aglabour and schedulcaste is 0.17 in the human casualty model.

[32] More than 50 percent of the population lives below the poverty line (Appendix Table A1).

[33] This is according to local folklore, post-cyclone vernacular stories (published in Suchitra Vijaya published from Bhubaneswar, Orissa) and newspaper-reporting in local dailies.

[34] The high casualty rate in villages near the coast was due to two reasons as suggested by the government officers and as confirmed by the villagers: (1) People did not take the warning seriously since low intensity cyclones are very common in that area (at least one every year) and people doubted the accuracy of government predictions of a super cyclone; (2) People also stayed back as they were scared of thefts of their valuables. They panicked only after the cyclone hit the area and then they tried to escape and were killed in the process.

[35] This study analyses only the village level or the rural household data.

[36] Though around 15 percent of the households have cemented wall (83 percent have mud wall), the material inside being either raw brick or mud, its capacity to withstand the super cyclone impact was doubtful.

House damages were described under three different categories by the state government—fully collapsed houses (either completely or 80 percent destroyed), partially collapsed houses (less than 80 percent damage) and swept away houses (wall as well as roof completely damaged due to storm surge). The study area for these models is a heterogeneous mixture of 365 villages and 138 gram panchayats covering the entire Kendrapada district and 86 coastal villages of the Kujang-Paradeep tahasil of the adjoining Jagatsinghpur district situated southeast of Kendrapada.[37]

Kujang-paradeep tahasil could be included in the house damage analysis, but not in the human death or livestock loss analysis.[38] The area covers 9 tahasils, eight from Kendrapada and one from the Kunjang-Pardeep tahasil of Jagatsinghpur. The explanatory variables used in these models are the same as those in the previous one. We used Male99 as proxy for properties at risk as no accurate measure of the total number of houses at risk was available.

6.2.1 Fully Collapsed Houses (FC)

The estimating equation for this model is similar to equation 13 except that the dependant variable now is FC.[39]

$$FC_i = \alpha_0 + \alpha_i Tahasildar_i + \alpha_2 velocitypow_i + \alpha_3 surge_i + \\ ---+\alpha_{28}\, nonwor\ker_i + v_i \quad \ldots\ldots\ldots\ldots \quad (14)$$

Expected Signs and Discussion

The expected signs for the coefficients are similar to the ones in the human casualties model except dmajriver. The major rivers play a protective role in the case of human deaths, but proximity to both major and minor rivers is likely to cause more house damage. The role of institutional variables like tahasildars in case of movable and immovable properties is widely different during natural calamities. The tahasildars are supposed to perform crucial duties during cyclones to save human lives and other movable property, but they can do little to save immovable property like houses. At the same time, the inclusion of tahasildar dummies in a regression equation that analyzes house damage due to cyclones is important because it is likely to capture the impact of any omitted variable present within a tahasil but with a perceptible impact on house

37 Village level data was available only for some tahasils; only gram panchayat level data was available for the others. To have a data set with uniform units, we tried to club the villages according to the gram panchayats they belong to, but the number of observations were reduced to 132 for sample 1 and to 89 for sample 2. Many villages had to be dropped from the sample, as we did not have data for other villages belonging to that gram panchayats. Regression results with only 132 and 89 observations did give similar results as the larger data set, but the level of significance was comparatively lower. The coefficient of mangrove variable was significant for both sample 1 and 2. But results for samples 3, 4 and 5 could not be tried due to very few observations. Hence, in spite of the heteroskedasticity problem, we used the larger data set.

38 Data on house damage for Kujang-Paradeep tahasil was available. However, being a high cyclone impact area (more than 8000 people had died in the Kujang block) information on human death and livestock was difficult to compile at the village level as this had to be aggregated over all individuals.

39 The error was heteroskedastic. We have used OLS estimates with robust standard errors for this model.

damage.[40] Table 7 and Appendix Table 15 give the expected signs as well as the estimated coefficients of the five regressions without and with the tahasildar dummies respectively. We use the velocitypow measure of radial wind in these equations.[41]

The robust OLS estimates of FC house models for all samples show that almost all the tahasildar dummies are significant either with a positive or negative sign depending on the sample area and the tahasil's proximity to the cyclone track (see Table 15). The dummy variable probably captures the locational effects of the cyclone in an aggregative manner rendering most of the other variables insignificant as house quality is nearly homogenous due to similar construction material used in the entire district. The results with tahasildar dummies are however less reliable due to high multicollinearity among explanatory variables as reflected by the values of variance inflation factors.[42]

The meteorological and geo-physical variables are significant with appropriate signs when we drop the tahsildar dummies (see Table 7). Hence, we use the results without tahasildar dummies for the discussion as well as the calculation of averted damages. The coefficients, wherever significant, have the appropriate sign and are as expected. The main cause of fully collapsed houses seems to be wind velocity. . Closeness to the river and coast also increased the damage. The mangrove variable in Appendix Table 15, though significant only for sample 3 (areas within 10km from coast), is significant with a negative sign for sample 1, 2 and 4 (Table 7). Thus we cannot reject the hypothesis that mangroves have reduced the number of fully collapsed houses.

6.2.2 Partially Collapsed Houses (PC)

We used the same set of regressors as used in HC and FC models for the PC model and obtained estimates with and without the tahasildar dummies for the five sample areas. We used Weighted Least Squares estimates for this model utilizing the area of the units as weight (see Table 8 and Appendix Table 16 respectively).[43]

---

[40] It could be some specific physical feature of the area or some traditional knowledge within the local community that helps them in constructing cyclone resistant houses; or it could be the perceptible economic prosperity of a tahasil compared to others, due to external reasons, which we have not included in the model.

[41] As stated earlier, the two measures of wind velocity, velocitypow and velocityexp, are highly correlated and the results are similar for both the measures in this model too. The correlation coefficient between velocitypow and velocityexp measures was around 0.95 for different samples.

[42] The variance inflation factor is defined as VIF = $1/(1-r_{ij})$, where r^2_{ij} is the coefficient of correlation between the i[th] and the j[th] regressor and var $(\hat{\beta}_i) = s^2/+x_i^2(1- r^2_{ij}) = s^2/+x_i^2 *$ VIF. Thus, VIF shows the extent to which the variance of an estimator gets inflated by the presence of multicollinearity. The VIF of some of the tahasils is as high as 60 and the prediction of averted damage due to mangrove presence with these coefficients may not be very reliable.

[43] The heteroskedasticity test was significant for this model and OLS with robust standard errors resulted in most of the variables being insignificant with wrong signs. Weighted Least Squares estimates, with both area and total population as weights, resulted in better results as well as expected signs of the coefficients. WLS does not control the heteroskedasticity problem completely, but using the robust option with WLS also leaves mangrove significant. However, as the WLS estimates are based on the a priori assumption that error variances are proportional to the variable used as weight, we also calculated the Feasible Generalized Least Squares (FGLS) estimates (Woolridge, 2003). FGLS estimates compared to WLS estimates with the same measure of wind velocity (velocitypow) had higher coefficients as well as t values, but since the variance inflation factors of these estimates were very high compared to WLS estimates, we did not use them for the final analysis.

Expected Signs & Discussion

In case of partially collapsed houses, we expect the coefficients to have the opposite signs to the ones derived for the FC model. As mentioned earlier, PC implies house damage varying from 10 percent to 80 per cent. Since there is no data on the actual amount of damage to houses, we could not test for the mangrove's protective services here. An indirect way would be to check whether the number of PC houses were more than the number of FC houses in the mangrove-protected areas. Thus, we expect a positive coefficient for the mangrove variable.[44]

This expectation is fulfilled as Mangrove is significant with a positive coefficient in all the tables (with or without tahasildar dummies) for all sample areas. Mangrove protected areas witnessed more partially collapsed houses than fully collapsed houses as mangroves offer reduced wind damages.[45] The other coastal forests, the casuarinas, seem to have played an opposite role, that is, its dummy is significant with a negative sign.

6.2.3 Swept Away Houses (SA)

Five different tahasils in the study area (Kuj-Pardeep, Mahakalapada, Rajnagar, Patamundai and Marshaghai) were reported to have been affected by storm surge but only the first 3 tahasils (adjoining the coast) witnessed swept away houses (Gupta and Sharma, 2000). The model of Swept Away houses uses a Tobit distribution for the dependant variable, the number of houses Swept Away (SA). The SA variable is a censored series, with value 0 for a large proportion of the observations (86 per cent). The range of the non-zero observations was also very high (0-1005).[46] We define a new variable (y) for the Tobit model:

$$y_i = 0 \text{ if } y_i^* \le 0,$$
$$y_i = y_i^* \text{ if } y_i^* > 0 \text{ and}$$
$$y_i^* = \beta' X_i + \omega_i \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (15)$$

where X_i are the set of explanatory variables, y_i is the transformed variable and w_i, is the error term. The latent variable (y_i*) is assumed to fulfill all classical linear model assumptions. We used only three tahasildar dummies[47] (the ones adjoining the coast) in computing the robust Tobit estimates (see Table 9). [48]

The extent of SA houses depends on water flow, which in turn depends on surface roughness. The tahasildar dummies capture the effects of coastline curvature (inverted U-shape), the bathymetry and the slope of land as these differ in the three coastal tahasils (Kalsi, et. al., 2004).

---

44 The coefficient of correlation between FC and PC houses is 0.26.

45 The coefficient of mangrove with the gram panchayat based data set was 67.86*** and 58.42*** for sample 1 and sample 2 respectively.

46 Though tobit distribution is assumed for continuous data, we can also use it over discrete observations if the range of non-zero observations is high (Woolridge, 2003).

47 The model did not converge if more than three Tahasil dummies were used. This may be because almost all of the swept away houses were from three tahasils.

48 Robust standard errors were calculated by using the interval regression estimates. We calculated these estimates because we expected heteroskedasticity problem due to heterogeneous units and moreover because the z-values also improved compared to the simple tobit estimates.

Expected signs and Discussion

The expected signs of the variables for swept away houses are the same as those of fully collapsed houses, as these were completely damaged houses.

The mangrove variable has a negative sign in all equations with tahasildar dummies, but none is significant. Hence the role of mangroves as a barrier to flooding-related damages to static properties cannot be established conclusively. Both topodumy and Mhabitat are significant with positive signs (only for sample 1). Low elevation and the hydrological features of mangrove habitat areas may have led to more houses being swept away indicating that the physical features of the place are the main determinant of water-related damage to houses. The surge variable is insignificant in all equations[49].

Among the other physical features, both droad and roaddumy are significant with positive signs for most of the areas. The significance of droad implies that villages near the highway (the only metalled road in the coastal area) did not witness many SA houses. The raised highway probably acted as a barrier to surge water. The opposite has happened in the case of roadumy. The village roads are mostly the salt-water dikes in coastal areas and they were constructed to stop the flow of seawater during high tides into agricultural lands. They were not effective in stopping the surge water.[50] The dikes, which helped save human lives (human casualties model), seem to have had the opposite effect in the case of houses.

6.3 Livestock Loss

Five types of livestock, i.e., cattle (cows, bullocks, calves and heifers), buffaloes, sheep, goat and poultry, were considered in the livestock loss model. However, we did not get any conclusive results for the three small animals (except in sample 2 for sheep). We therefore discuss the results for cattle and buffaloes only.[51] The cattle population is evenly spread throughout the study area, and they are kept mostly for domestic purposes. Buffaloes are raised only for commercial purposes and are kept in fenced areas outside the village. They are found only in limited areas, but are kept in large herds due to economies of scale. The livestock loss figures were available at the village gram panchayat level for only Kendrapada district. We used the same set of explanatory

---

49 As mentioned earlier, the variable flooding1 (= surge * exp (-dcoast)) was used in place of surge just to check if it improves the result. Surprisingly, the results came much improved and flooding1 came out significant (only in sample2) indicating that assuming the level of surge water to be decreasing exponentially with coastal distance can explain the damages data better. These results with flooding1 in place of surge are shown in Appendix Table 17. The most significant results using flooding1 in place of surge are that the mangrove is significant with negative sign for both sample2 and storm surge affected areas in the presence of the tahasildar dummies, though the coefficients are very small. Thus, the possibility of mangroves having some dampening effect on flooding damages cannot be ruled out. At the same time, this result is not very conclusive as the variable flooding1 is only a crude measure. The correct measure of level of flooding could have been flooding1 = surge* exp (-a*dcoast), but we have ignored the value of a, as it was not known.

50 In many places, as reported by eyewitnesses and volunteers, dikes got breached helping the surge water to enter the villages easily, but the water did not get drained out quickly due to the dikes causing damage to houses (ActionAid India/BGVS, 2000).

51 We collected data on all types of cyclone damage from the government departments. The compilation of the loss figures by these departments were mainly on the basis of the compensation paid for the damages. As no compensation was paid for the loss of small animals, probably the loss figures maintained by the veterinary office were only approximate numbers. This could have been a reason why we did not get any significant results.

variables as in the previous models with male99 being replaced by the total population of the respective livestock as calculated for the year 1999.

Buffalo loss was reported from 61 panchayats. Since the dependent variable was a count with a large number of zeroes and a low range of non-zero values, a robust Poisson distribution was assumed.[52] We used OLS with robust standard error for cattle. We present estimates for only sample 1 and 2 due to the small number of observations for other sample areas.

Livestock are movable property and evacuation would therefore be theoretically possible before a cyclone. However, during the 1999 cyclone, due to short notice, all effort was directed to evacuate human beings.[53] Those owning concrete house kept their livestock inside the house. However, the majority of the livestock were left outside and suffered heavily.[54]

Expected signs & Discussion

The expected signs for all the variables (except cultivators and marginal workers) for both types of livestock are similar to the human casualty model. Cultivators have a high holding of cattle but do not own concrete houses and are therefore expected to have a positive sign for cattle. For the same reason, we expect marginal workers to have a positive sign for buffalo (see Table 10). Of the three mangrove-related variables, mangrove vegetation is significant with a negative sign for buffalo loss (only sample 1) and cattle loss (both the sample areas). Mhabitat is significant with a positive sign for both buffalo and cattle (only sample 1) and topodumy is significant with a positive sign only for buffalo loss. But the results improved after some re-specification of the models.[55]

Thus, the pattern of results is similar to the human casualty and house damage models. Mangrove vegetation seems to provide protection, whereas the physical features of the mangrove habitat area (topodumy and mhabitat) increase the damage. Though the effect of mangroves in saving livestock is neither robust nor confidently established (the level of significance is only 10 percent whenever significant), its protective capacity cannot be ruled out.

7. Discussions and Policy Implications

This study establishes that mangroves were highly effective in reducing casualties during the Super Cyclone, whether of humans, buffaloes or cattle. Elasticity[56] estimates indicate that if the

---

[52] The regression based over dispersion test (Green, 2000) was significant for this model (á=16.89, t-value=7.04 and P=0.00). The negative binomial estimates were all insignificant whereas we found the robust Poisson estimates to be comparatively better. As robust standard errors in Poisson model can deal with any kind of dispersion problem consistently, we used robust Poisson estimates for the buffalo loss model (Constant and Zimmerman, 2003).

[53] Personal correspondence with the emergency officer, Kendrapada.

[54] The models without the tahsildar dummies were used here.

[55] Mangroves become significant with negative sign and Mhabitat with positive sign for both samples if we drop non-workers from the cattle model and both non-workers and literates from the buffalo model. As seen in table 10, these alternative specifications do not change the F value and the Wald Chi square value of these models. We did this to ease the multicollinearity in the models.

[56] Elasticity is calculated by the formulae $\partial \log y / \partial \log x$, where y is the dependant variable and x is the i^{th} independent variable. The elasticity of a variable in a Poisson model equals the estimated coefficient times the average value of the independent variable, whereas for linear models, it equals the estimated coefficient times the ratio of the average values of the independent variable to the dependent variable.

width of the mangroves was 10% more than its 1999 status, there would have been a further reduction in human casualties by 12.48 %, buffalo loss by 6.6 % and cattle loss by 2.23 % (see Table 11). Increase in mangrove width would have also reduced the number of fully collapsed houses by 2.21%, and increased the number of partially collapsed houses by 2.17 % implying that complete damage is converted to partial damage due to the presence of mangroves. Mangroves do not seem to have much of an impact on swept away houses.[57]

The combined elasticity of topodumy and mhabitat, where significant, is less than the elasticity of mangrove vegetation only for human death and more for all other types of damage. These results indicate that human death can be greatly reduced by having mangroves in the areas which had mangroves historically, but other damage reduction is comparatively less responsive. In addition, land elevation and immovable asset holdings also impacted human death, mainly in storm surge affected areas.

Low-lying areas will need evacuation before a cyclone whether or not mangroves are present. Moreover, mangroves were not able to reduce the number of swept away houses (protection from flooding due to surge). Factors like low elevation, other physical features of mangrove habitat areas, the presence of village roads (dikes), etc., increased the number of swept away houses.

In sum, mangroves have a proven ability as natural barriers against cyclones. It is effective against the wind and wave surges during natural calamities which are frequent in this area. Since mangroves don't seem to be as effective against flooding in low lying areas, these areas need to be completely evacuated before cyclones. Coastal areas which currently have mangroves or had mangroves in the past need special developmental plans keeping in mind the vulnerability and risks that human lives, livestock and immovable assets face in these areas. Conservation and regeneration of mangroves in coastal areas is a necessity to reduce damages from natural calamities which occur frequently in these areas.

8. Acknowledgements

I would like to acknowledge the financial support from the South Asian Network for Development and Environmental Economics (SANDEE) and encouragement from Priya Shyamsunder and Pranab Mukhopadhyay. I am grateful to Jeffrey Vincent for his useful suggestions and valuable comments. I would also like to thank Kanchan Chopra for all her encouragement and guidance. I gratefully acknowledge the help of K. L. Krishna and other SANDEE resource persons at different stages of my work. I thank Charan Singh, Meteorologist, Government of India, and Sushil Kumar Dash, Head of the Department of Atmospheric Sciences, IIT, Delhi, for clarifying the meteorological theories and making the meteorological information available. I am very grateful to Jual Oram, former Minister, Government of India, Jatindra Das, Special Correspondent, IANS, and the Emergency Officers of Kendrapada and Jagatsinghpur district for providing cyclone damage data. A special thank you goes to the staff members of the Emergency Office, CDVO Office, and the *tahasildar* office of Kendrapada district for their enthusiastic support. I am also grateful to Bibhu Prasad Nayak and Vikram Dayal for their substantial help and to Nityanand Patnaik and Ashitaa Dawar for providing efficient research assistance.

[57] The decline in the number of swept away houses would have however been only 0.4% (if the result with flooding1 is taken); it does not have any impact otherwise on swept away houses.

References

ActionAid India/BGVS (2000), “Base paper on Sustainable Embankment Project and Settler’s Right”, Jagatsinghpur: Super Cyclone Social Reconstruction Project, Mimeograph.

Badola, Ruchi and S. H. Hussain (2005), “Valuing ecosystem functions: an empirical study on the storm protection function of Bhitarkanika mangrove ecosystem, India”, *Environmental Conservation,* 32: 1-8.

Baird, Andrew H. (2006), “Viewpoint: Tsunamis: Myth of green belts”, SAMUDRA, Report No.44, July, Triannual Report of the International Collective in Support of Fishworkers, Belgium,14-19.

Basu, B. K. and S. K. Ghosh (1987), “A model of surface wind field in a tropical cyclone over Indian Seas”, *Mausam*, 35: 183-522.

Bretschneider, C. L. and P. G. Wybro (1977), “Tsunami Inundation Prediction”, Ed. C. L. Bretschbeider, Proceedings of the 15th Coastal Engineering Conference, New York: American Society of Civil Engineers, 1006-1024.

Chan, H. T., *et. al*., (1993), “The socio-economic, ecological and environmental values of mangrove ecosystems in Malaysia and their present state of conservation”, Ed. B. F. Clough, *The economic and environmental values of mangrove forests and their present state of conservation in south-east Asia/Pacific Region*, Vol.1, International Society for Mangrove Ecosystems, Okinawa: International Tropical Timber Organization and Japan International Association for Mangroves, 41-81.

Chatenoux, B. and P. Peduzzi (2006), “Analysis of the Role of Bathymetry and Other Environmental Parameters in the Impacts from the 2004 Indian Ocean Tsunami”, UNEP/DEWA/ GRID-Europe, Switzerland:

http://www.grid.unep.ch/product/publication/download/environment_ impacts_tsunami.pdf

— (2007), “Impacts from the 2004 Indian Ocean Tsunami: Analyzing the potential protecting role of environmental features”, *Natural Hazards*, 40: 289-304.

Cochard, R.,,*et. al.,* (2008), “The 2004 tsunami in Aceh and Southern Thailand: A review on coastal ecosystems, wave hazards and vulnerability,” *Perspectives in Plant Ecology, Evolution and Systematics,* 10: 3-40.

Constant, Ameli and K. F. Zimmermann (2003), “Circular Movement and Time away from Host Country”, IZA (The Institute for the Study of Labor), Discussion Paper No. 960, Bonn, Germany.

Dahdouh-Guebas, F. and Nico Koedam (2006), “Coastal Vegetation and Asian Tsunami”, *Science,* 311: 37.

Dahdouh-Guebas**,** F., (2006), “Mangrove forests and tsunami protection”, *McGraw-Hill Yearbook of Science & Technology 2006*, McGraw-Hill Professional, New York, USA, 187-191.

Das, P.K. (1972), “Prediction model for storm surges in the Bay of Bengal”, *Nature*, 239: 211-213.

Das, P. K., M. C. Sihna and V. Balasuburamanyam (1974), "Storm Surges in Bay of Bengal", *Quarterly Journal of Meteorological Society*, 100 (425): 437-449.

Das, Saudamini (2007), "Storm Protection Value of Mangroves in Coastal Orissa", in P Kumar and B. Sudhakar Reddy (ed), *Ecology and Human Well-Being*, Sage Publications, Delhi, 197-212.

Dixon, John A. *et. al*., (1994), *Economic Analysis of Environmental Impacts* (2nd ed.), London: Earthscan Publication in Association with the Asian Development Bank and the World Bank.

Dube, S. K., P. C. Sihna and A. D. Rao (1981), "The response of different wind stress forcing on the surge along the east coast of India", *Mausam*, 32: 315-320.

FAO (2006), "Coastal Protection in the aftermath of the Indian Ocean Tsunami: what role for forests and trees?" Concept Note, Conclusion and Policy Recommendation, Regional Technical Workshop, 28-31 August, Khao Lak, Thailand.

FAO (2000), "Reducing Agricultural Vulnerability to storm related disasters", COAG 01/6, FAO Corporate Document Repository, Annexure, XI, APDC/01/7.

Farber, S. (1987), "The value of coastal wetlands for protection of property against Hurricane wind damage", *Journal of Environmental Economics and Management*, 14: 143-151.

Forest Survey of India (2001), "The State of Forest Report", Government of India, Dehradun.

Fosberg, F. R. (1971), "Mangroves versus tidal waves", *Biological Conservation*, 4:

38-39.

Ghose, S.K. (1977), "Prediction of Storm Surge on the East Coast of India", *Journal of Meteorological Hydrology and Geophysics*, 28 (2): 157-168.

Ghose, S. K. (1995), "Storm Surges and their Numerical Prediction along Indian Coasts", *Indian Meteorological Department Forecasting Manual*, IV-24, Govt. of India, August 1995.

GoO (2004), "Status of Mangroves in Orissa", Wild Orissa,Wild Life Division, Forest Department, Government of Orissa, Bhubaneswar, October.

Greene, W. H. (2000), *Econometric Analysis* (4th Edition), Delhi: Pearson Education Asia.

Gupta, M. C. and V. K. Sharma (2000), *Orissa Super Cyclone 99*, National Center for Disaster Management, Indian Institute of Public Administration, New Delhi: New United Press.

Halversen, R. and R. Palmquist (1980), "The interpretation of Dummy Variables in Semi-logarithmic Equations", *American Economic Review*, 70: 474-75.

Harada, K. and F. Imamura (2005), "Effects of Coastal Forests on Tsunami Hazard Mitigation, a preliminary investigation", *Advances in Natural and Technological Hazards Research*, (23): 279-292.

HDR (2004), Human Development Report (Prepared by Nabakrushna Choudhury Centre for Development Studies), Planning and Co-ordination Department, Bhubaneswar: Government of Orissa.

Holland, G. H. (1980), “An analytical model of tropical and pressure profiles in Hurricanes”, *Monthly Weather Review*, 108: 1212-18.

IMD (2002), “Damage Potential of Tropical Cyclones”, New Delhi: Indian Meteorological Department, Govt. of India.

IMD (2000), “Tracks of Cyclones in Bay of Bengal and Arabian sea, 1890-1990”, New Delhi: Indian Meteorological Department, Govt. of India.

Jalesnianski, C. P. (1965), “A numerical calculations of storm tides induced by a tropical storm impinging on a continental shelf”, *Monthly Weather Review,* 93: 345-358.

Kalsi, S.R., N. Jayanthi and S. K. Roy Bhowmik (2004), “A Review of different storm surge models and estimated storm surge height in respect of Orissa Supercyclonic storm of 29 October, 1999”, Indian Meteorological Department, Govt. of India.

Kalsi, S. R., S. D. Kotal and S. K. Roy Bhowmick (2003), “Decaying Nature of Super Cyclone of Orissa after landfall”, *Mausam,* 54 (2): 393-396.

Kaplan, J. and M. Demaria (1995), “A simple empirical model for predicting the decay of tropical cyclone wind speed after land-fall’, *Journal of Applied Meteorology*, 34: 2499-2512.

Kerr, A.M. and A. H. Baird (2008), “Landscape Analysis and Tsunami Damages in Aceh: Comment on Iverson and Prasad (2007)”, *Landscape Ecology*, 23: 3-5.

—- (2007), “Natural Barriers to Natural Disasters”, *Bio-Science*, 57 (2): 102-103.

Khazai, B., J. C. Ingram and David S. Saah (2007), “The Protective Role of Natural and Engineered Defence Systems in Coastal Hazards”, Report prepared for the State of Hawaii and the Kaulunani Urban and Community Forestry Program of the Department of Land and Natural Resources, Spatial Informatics Group, CA, USA.

Massel, S. R., K. Furukawa and R. M. Brinkman (1999), “Surface wave propagation in mangrove forests”, *Fluid Dynamics Research*, 24: 219-249.

Mazda, Y. M. Magi, M. Kogo and P.N. Hong (1997), “Mangroves as a coastal protection from waves in the Tong King Delta, Vietnam”, *Mangroves and Salt Marshes,* 1: 127-135.

Mazda, Y, M. Magi, et. al., (2006), “Wave reduction in a mangrove forest dominated by Sonneratia sp.”, *Wetlands Ecology and Management*, 14: 365-378.

ODG (1996) Orissa District Gazetteer — Cuttuck, The Gazetteers Unit, The Department of Revenue, Bhubaneswar, Government of Orissa.

Quartel, S., et. al., (2007), “Wave attenuation in coastal mangroves in Red River Delta, Vietnam”, *Journal of Asian Earth Sciences*, 29: 576-584.

Roy Abraham, K., U. C. Mohanty and S. K. Dash (1995), “Simulation of Cyclones using synthetic data”, *Proceedings of the Indian Academy of Sciences, Earth and Planetary Sciences*, 1044635-666.

Singh, Charan and B. K. Bandyopadhyay (2005), "Decaying characteristics of severe cyclonic storms after landfall over east coast of India," *Mausam* 2: 395-400.

Steffen, W. (2006), "Stronger Evidences but new Challenges: Climate Change Science 2001-2005", Department of Environment and Heritage, Australian Green House Office, Government of Australia.

Wooldridge, J. M. (2003), *Introductory Econometrics: A Modern Approach,* Ohio, Thomson Press.

TABLES

Table 1: List of Variables (alphabetically)

Variables	Definition of variables (all distances in kilometers)
Aglabour	Percentage of agricultural laborers in a village.
Barrier	Wind barriers present along the wind direction
Casurindmy	Dummy variable for the presence of casuarinas forest in coastal distance of a village.
Cultivator	Percentage of cultivators in a village
Dcoast	Minimum distance of a village from the coast.
Dcypath	Minimum (radial) distance of a village from the path of cyclone.
"i"	Location subscript
D	Damage suffered (loss of human life, loss of livestock and damage to residential structures) in the ith location (village)
Dmajriver	Minimum distance of a village from a major river (directly connected to sea).
Dminriver	Minimum distance of a village from a minor river (a tributary of major river)
Droad	Minimum distance of a village from a metallic road
Hhworker	Percentage of people working in (own) household industries in a village.
Literate	Percentage of literate people in a village
Mangrove	Width of existing mangrove forest in coastal distance of a village.
Margworker	Percentage of marginal workers in a village.
Mhabitat	Width of the historical mangrove forest (as existed in 1950) in coastal distance of a village or in between a village and the coast.
Nonworker	Percentage of non-workers (old dependants, housewives, students, children etc.) in a village.
Otworker	Percentage of other workers (doctor, teacher, engineer, barber, washer man, priest etc.) in a village
P	Population or property at risk

Pop99	Total population of a village in 1999
R, *a, B*	R is the radius of the eye of the cyclone (15 km in the present case), and are parameters specific to different cyclones. a = 0.6 and B = 240 for super cyclone of 1999.
Radial wind	The expected wind velocity at different radial distances (dcypath) from the cyclone eye
Roadumy	Dummy variable for the presence of village road (=1, if village road exists, =0, otherwise)
RW	Radial wind
Schdulcaste	Percentage of scheduled caste people in a village.
S	Socio-economic factors influencing extent of damages.
Surge	Level of sea elevation (in meters)
Tahasildar	Dummy variable for local administration and sub-district features
Topodmy	Low elevation dummy (=1 for villages that have or had mangrove earlier and = 0 for others)
Velocityexp	Approximate radial wind velocity (kmh-1) in a village due to cyclone as given by an exponential function
Velocitypow	Approximate radial wind velocity (kmh-1) in a village due to cyclone as given by a power function
V	*Velocity of wind*
Vmax	Maximum wind velocity at the eye wall region of a cyclone
W	Velocity or the severity of flooding due to storm surge
RW	Radial wind
Schdulcaste	Percentage of scheduled caste people in a village.
S	Socio-economic factors influencing extent of damages.
Surge	Level of sea elevation (in meters)
Tahasildar	Dummy variable for local administration and sub-district features
Topodmy	Low elevation dummy (=1 for villages that have or had mangrove earlier and = 0 for others)
Velocityexp	Approximate radial wind velocity (kmh-1) in a village due to cyclone as given by an exponential function

Velocitypow	Approximate radial wind velocity (kmh-1) in a village due to cyclone as given by a power function
V	Velocity of wind
V_{max}	Maximum wind velocity at the eye wall region of a cyclone
W	Velocity or the severity of flooding due to storm surge

Table 2: Descriptive Statistics for the 3 Models (Sample 1)

	Human Casualties, N=864		House Damage, N=516		Livestock Loss, N=143	
Variables	Mean (Std.dev)	Min (Max)	Mean (Std.dev)	Min (Max)	Mean (Std.dev)	Min (Max)
Dcypath	32.78 (18.83)	0.62 (83)	19.20 (10.98)	0.22 (72.83)	22.47 (16.09)	0.62 (72.83)
Velocitypow	134.40 (40.21)	68.13 (190.16)	163.19 (23.80)	73.64 (190.16)	155.62 (36.84)	73.64 (190.16)
Velocityexp	176.61 (12.96)	143.24 (190.16)	185.29 (7.50)	149.44 (190.16)	182.77 (10.14)	149.44 (190.16)
Surge	2.01 (1.73)	0.6 (5.9)	3.14 (2.04)	0.7 (5.9)	3.21 (2.09)	0.7 (5.9)
Dcoast	22.99 (13.49)	0.34 (51.23)	26.65 (14.67)	0.65 (51.23)	23.01 (11.34)	2.19 (49.33)
Topodmy	0.11 (0.31)	0 (1)	0.13 (0.33)	0 (1)	0.06 (0.34)	0 (1)
Mhabitat	4.62 (2.67)	0.2 (14.1)	4.58 (1.85)	0.5 (13.7)	4.19 (2.07)	1.22 (11.2)
Mangrove	1.46 (2.38)	0 (10)	0.46 (0.91)	0 (10)	0.74 (1.61)	0 (10)
Casurindmy	0.24 (0.42)	0 (1)	0.37 (0.48)	0 (1)	0.37 (0.48)	0 (1)
Dmajriver	3.52 (3.41)	0.05 (22.21)	4.01 (3.32)	0.06 (16.66)	3.91 (2.94)	0.08 (14.11)
Dminriver	2.98 (2.78)	0.08 (15.28)	3.21 (3.21)	0.08 (15.23)	2.94 (2.73)	0.12 (15.43)
Droad	2.66 (2.57)	0.02 (14.29)	2.21 (2.57)	0.02 (15.68)	2.62 (2.86)	0.05 (15.26)
Roadumy	0.75 (0.43)	0 (1)	0.80 (0.39)	0 (1)	0.92 (0.28)	0 (1)
Pop99	991.74 (1090.27)	6 (7545)	768.27 (863.81)	3 (5340)	---	---
Literate	0.63 (0.11)	0 (0.9)	0.66 (0.90)	0.19 (1)	0.65 (0.06)	0.46 (0.75)
Schdulcaste	0.18 (0.18)	0 (1)	0.21 (0.17)	0 (1)	0.22 (0.10)	0 (0.65)

Schdulcaste	0.18 (0.18)	0 (1)	0.21 (0.17)	0 (1)	0.22 (0.10)	0 (0.65)
Cultivator	0.13 (0.09)	0 (1)	0.12 (0.05)	0 (0.42)	0.10 (0.04)	0.02 (0.24)
Aglabour	0.05 (0.06)	0 (1)	0.04 (0.08)	0 (0.25)	0.05 (0.02)	0.004 (0.12)
Hhworker	0.003 (0.007)	0 (0.07)	0.004 (0.007)	0 (0.07)	0.004 (0.005)	0 (0.04)
Otworker	0.06 (0.04)	0 (0.28)	0.06 (0.04)	0 (0.36)	0.05 (0.02)	0.02 (0.15)
Margworker	0.09 (0.11)	0 (0.56)	0.08 (0.08)	0 (0.57)	0.07 (0.06)	0.01 (0.36)
Nonworker	0.66 (0.14)	0 (0.99)	0.68 (0.09)	0 (0.83)	0.70 (0.06)	0.43 (0.83)

Table 3: Summary of Regressions Used

Name of the dependent variable	Type of Damage	Unit of Analysis	No of Observations in the Sample-1	Type of Data	Estimates Used
Sucyduth	Human death due to super cyclone	Village	840 (656 zeroes and 184 non-zeroes)	Count, most of the observations are either 0 of 1, Range (0-21).	Simple Poisson estimates
FC	Houses fully collapsed (FC)	Both villages and gram panchayats	516 (only 3 zeroes)	Continuous Range = (0-1885) Heteroskedasticity test significant. Brausch-Pagan Chi 2= 526.47 (Pro = 0.00)	Robust OLS.
PC	Houses partially collapsed (PC)	Both villages and gram panchayats	516 (only 3 zeroes)	Continuous. Range = (0-2364) Heteroskedasticity test significant. Breusch-Pagan Chi 2 = 1279.97) (Pro = 0.00)	Both WLS and FGLS
SA	Houses swept away (SA)	Both village and gram panchayat	516 (449 zeroes and 67 non-zeroes)	Censored data as swept away houses were found near the coast or near major rivers (Range = 0-1005)	Robust Tobit (Interval Regression)
Buffaloes lost	Dead buffaloes	Gram Panchayat	68 (28 zeroes and 40 non-zeroes)	Count data. Most of the observations are either 0 or less than 40 (Range = 0-121)	Robust Poisson

Buffaloes lost	Dead buffaloes	Gram Panchayat	68 (28 zeroes and 40 non-zeroes)	Count data. Most of the observations are either 0 or less than 40 (Range = 0-121)	Robust Poisson
Cattle Lost	Dead cattle	Gram Panchayat	143 (all non-zeroes)	Continuous. Range= (0-1006) Heteroskedasticity test significant BP chi 2 = 16.21 (P = 0.00)	Robust OLS
Sheep lost	Dead sheep	Gram panchayat	143 (all non zeroes)	Continuous. Range= 0-651, Heteroskedasticity test significant BP chi 2 = 486.64 (P = 0.00)	Robust OLS
Goat Lost	Dead goats	Gram Panchayat	143 (all non zeroes)	Continuous. Range = (0-281) Heteroskeldasticity test significant BP chi 2 = 13.21 (P = 0.00)	Robust* OLS
Poultry Lost	Dead Poultry	Gram Panchayat	143 (all non zeroes)	Continuous. Range = (0-2530) Heteroskedasticity test significant, BP chi 2 = 188.39 (P = 0.00)	Robust OLS

* Both Poisson as well as FGLS also gave similar results.

Table 4: Poisson Estimates for Human Casualties Model with *Tahasildar* Dummies (Wind measure = velocitypow)

Equation/ variable	Exp.signs	Sample-1 ,	Sample-2,	Sample-3,	Sample-4,	Sample-5,
Mahakalpada	(?)	0.34 (0.31)	0.46 (0.41)	16.52 *** (4.58)	0.03 (0.02)	1.74 *** (3.60)
Rajnagar	(?)	-1.49 (1.36)	-1.59 (1.30)	15.34*** (5.80)	Dropped	Dropped
Rajkanika	(?)	-14.91 (0.03)	-16.01 (0.02)	Dropped	-15.63 (0.02)	Dropped
Patamundai	(?)	-1.35 (1.21)	-1.25 (1.10)	13.55*** (3.87)	-0.88 (0.59)	0.01 (0.02)
Aul	(?)	Dropped	Dropped	Dropped	Dropped	Dropped
Garadpur	(?)	0.04 (0.03)	Dropped	Dropped	Dropped	Dropped
Marsaghai	(?)	0.38 (0.32)	Dropped	Dropped	0.99 (0.52)	1.27 (0.96)
Kend-derabis	(?)	0.32 (0.27)	0.74 (0.67)	Dropped	0.91 (0.58)	Dropped
Bhadrakh	(?)	Dropped	-0.39 (0.23)	Dropped	-0.14 (0.08)	Dropped
Velocityexp	(+)	-0.023*** (4.69)	-0.03*** (4.54)	-0.01 (0.37)	-0.02 ** (2.32)	-0.04*** (3.48)
Surge	(+)	0.22*** (3.65)	0.21*** (3.05)	0.22 (1.33)	0.03 (0.39)	0.19** (2.15)
Dcoast	(-)	0.008 (0.54)	0.004 (0.27)	0.45 *** (3.02)	-0.01 (1.12)	0.03 (0.93)
Topodumy	(+)	0.40 * (1.85)	0.27 (1.15)	2.27 *** (3.55)	-1.49 * (1.94)	0.62 ** (2.16)
Mhabitat	(?)	0.08*** (2.99)	0.12*** (3.43)	-0.43*** (2.92)	0.25 *** (3.95)	0.13*** (2.96)
Mangrove	(-)	-0.81*** (4.30)	-0.73*** (4.00)	-1.48 *** (3.73)	-0.57 ** (2.47)	-0.64*** (3.99)
Casurinadumy	(-)	0.12 (0.73)	0.20 (1.03)	-0.27 (0.53)	0.99*** (3.74)	0.11 (0.53)

Dmajriver	(+)	0.05** (2.49)	0.06** (2.47)	0.15 (1.27)	0.04 (1.44)	0.04 (1.15)
Dminriver	(-)	-0.07** (2.56)	-0.06* (1.66)	-0.13 (1.18)	-0.04 (0.93)	-0.15 ** (2.17)
Droad	(+)	-0.05* (1.61)	-0.04 (1.04)	0.005 (0.05)	0.04 (0.56)	0.01 (0.33)
Roadumy	(-)	-0.21 (1.41)	-0.38** (2.24)	-0.09 (0.24)	-0.11 (0.48)	-0.51*** (2.66)
Pop99	(+)	0.0004*** (9.03)	0.0005*** (9.61)	0.0006***(-6.21)	0.0005*** (5.00)	0.0006*** (8.95)
Literate	(-)	-1.28* (1.81)	-0.43 (0.54)	-2.69 ** (2.12)	2.45 * (1.85)	0.58 (0.67)
Schdulcaste	(+)	-0.92** (2.12)	-1.60*** (3.00)	-2.92 * (1.63)	-0.78 (1.11)	-2.60*** (3.31)
Cultivator	(-)	-0.78 (1.21)	-2.03** (2.12)	-2.70 (1.41)	-2.90 * (1.81)	-2.95*** (2.85)
Aglabour	(+)	-0.11 (0.17)	-0.12 (0.21)	-1.06 (0.33)	5.31 ** (2.56)	-0.57 (0.39)
Hhworker	(-)	8.59 (1.10)	14.03 (1.47)	9.71 (0.33)	9.78 (0.92)	39.65*** (3.30)
Otworker	(-)	-1.77 (1.11)	-2.52 (1.43)	-5.69 * (1.79)	-3.73 (1.20)	-3.94** (2.05)
Margworker	(+)	0.86 (1.29)	0.81 (1.11)	2.81 ** (2.18)	-0.70 (0.49)	0.71 (0.79)
Nonworker	(-)	-0.34 (1.19)	-0.29 (0.73)	-0.83 (0.75)	0.26 (0.27)	0.14 (0.22)
Constant	(?)	2.96** (2.31)	3.45** (2.11)	-15.37 (0.01)	-1.05 (0.54)	1.74 (1.47)
N		N=840, R2=0.39	N=771, R2=0.41	N=155, R2=0.60	N=556, R2=0.34	N=364, R2=0.42
		LR Chi2 (27)= 736.97, Pro = 0.00, Pseudo	LR Chi2 (26) = 594.26, Pro = 0.00, Pseudo	LR Chi2 (23)= 319.1, Pro = 0.00, Pseudo	LR Chi2 (26)=290.0-1, Pro = 0.00, Pseudo	LR Chi2 (23)=423.16 Pro = 0.00,

Notes: - The figures in parenthesis in all tables are the absolute z or t-values and * implies significant at 1%, ** implies significant at 5% and * implies significant at 10% level of significance.**

Table 5: Negative Binomial Estimates for Human Casualties Model with Tahasildar Dummies (Wind Measure = Velocitypow)

Variable	Exp.sign	Sample-1	Sample-2	Sample-3	Sample-4	Sample-5
Mahakalpada	(?)	-0.05 (0.04)	0.23 (0.14)	Dropped	-0.54 (0.31)	1.36* (1.78)
Rajnagar	(?)	-1.59 (1.24)	-1.52 (0.87)	18.72*** (13.43)	Dropped	Dropped
Rajkanika	(?)	-15.25 (0.03)	-14.52 (0.05)	Dropped	-15.07 (0.03)	Dropped
Patamundai	(?)	-1.60 (1.21)	-1.21 (0.75)	16.36*** (6.15)	-1.26 (0.76)	0.04 (0.06)
Aul	(?)	Dropped	Dropped	Dropped	Dropped	Dropped
Garadpur	(?)	-0.50 (0.34)	Dropped	Dropped	Dropped	Dropped
Marsaghai	(?)	0.15 (0.11)	Dropped	Dropped	0.17 (0.07)	0.37 (0.18)
Kend-derabis	(?)	-0.13 (0.09)	0.70 (0.44)	Dropped	0.42 (0.23)	Dropped
Bhadrakh	(?)	Dropped	-0.16 (0.07)	Dropped	-0.06 (0.03)	Dropped
Velocityexp	(+)	-0.02*** (3.31)	-0.03*** (3.30)	-0.05* (1.70)	-0.02* (1.82)	-0.03* (1.76)
Surge	(+)	0.22** (2.59)	0.21* (1.84)	0.67*** (2.97)	0.04 (0.30)	0.31 (1.47)
Dcoast	(-)	0.01 (0.78)	0.01 (0.39)	0.14 (0.97)	-0.007 (0.36)	0.05 (1.14)
Topodumy	(+)	0.48 (1.48)	0.47 (1.26)	-1.96 (0.91)	-1.56 (1.57)	0.72 (1.18)
Mhabitat	(?)	0.10 *** (2.60)	0.18*** (3.29)	-0.10 (0.71)	0.27*** (3.41)	0.11 (1.18)
Mangrove	(-)	-0.72*** (3.80)	-0.66*** (3.88)	-1.70*** (2.83)	-0.63*** (2.61)	-0.59*** (3.30)
Casurinadumy	(-)	0.17 (0.75)	0.27 (0.95)	-0.55 (0.95)	0.94** (2.37)	0.10 (0.26)
Dmajriver	(+)	0.06 ** (2.16)	0.08 ** (2.34)	0.24* (1.76)	0.05 (1.51)	0.08* (1.63)
Dminriver	(-)	-0.06 * (1.74)	-0.06 (1.17)	-0.05 (0.44)	-0.04 (0.76)	-0.14 (1.39)
Droad	(+)	-0.05 (1.19)	-0.02 (0.32)	-0.09 (1.12)	0.04 (0.41)	0.04 (0.64)

Roadumy	(-)	-0.17 (0.85)	-0.22 (0.95)	-0.61 (1.46)	0.02 (0.08)	-0.47 (1.53)
Pop99	(+)	0.0005*** (6.44)	0.0006*** (5.86)	0.0007*** (6.03)	0.0006*** (4.08)	0.0006*** (5.07)
Literate	(-)	-1.44 (1.51)	-0.28 (0.24)	-3.05* (1.87)	1.53 (0.86)	0.18 (0.19)
Schdulcaste	(+)	-0.84 (1.46)	-1.18* (1.61)	-2.62 (1.32)	-0.80 (0.88)	-2.55** (2.20)
Cultivator	(-)	-0.60 (0.70)	-1.69 (1.32)	-0.55 (0.30)	-1.37 (0.68)	-2.24 (1.43)
Aglabour	(+)	0.14 (0.08)	0.30 (0.16)	-2.36 (0.66)	2.96 (1.00)	0.02 (0.01)
Hhworker	(-)	6.68 (0.58)	9.96 (0.70)	7.40 (0.22)	-0.22 (0.14)	30.43 (1.52)
Otworker	(-)	-2.27 (1.00)	-1.45 (0.53)	-1.97 (0.59)	-0.48 (0.12)	-1.73 (0.49)
Margworker	(+)	1.26 (1.37)	1.34 (1.26)	3.14** (2.27)	0.39 (0.22)	0.94 (0.72)
Nonworker	(-)	0.13 (0.20)	-0.04 (0.04)	-0.24 (0.24)	0.22 (0.15)	0.13 (0.13)
Constant	(?)	2.43 (1.50)	2.34 (0.98)	-12.69*** (2.78)	-0.81 (0.34)	0.74 (0.34)
Likelihood-ratio test for alpha = 0	82.12, Pro=0.00	77.02, Pro=0.00	1.33, Pro=0.125	40.52, Pro=0.00	80.87, Pro=0.00	
	N=840, LR Chi2 (27)= 319.66, P = 0.00, Pseudo R2=0.23	N=771, LR Chi2 (26) = 231.60, P = 0.00, Pseudo R2=0.23	N=155, LR Chi2 (22)= 98.21, P = 0.00, Pseudo R2=0.31	N=556, LR Chi2 (26)=149.1-6, P = 0.00, Pseudo R2=0.22	N=364, LR Chi2 (23)=111.5-2 P= 0.00, Pseudo R2=0.18	

Table 6: Marginal Effect of Mangrove Related Variables on Human Casualties
(Marginal effects based on table-4)

Variable/ area	Topodumy	Mhabitat	Mangrove
Sample-1	0.0074	0.00013	-0.0128
Sample-2	0.0011	0.00046	-0.00275
Sample-3	0.3487	-0.0475	-0.1584
Sample-4	-0.0030	0.0009	-0.0021
Sample-5	0.1263	0.0353	-0.1166

Table 7: OLS Estimates with Robust Std. Errors for Fully Collapsed Houses without the Tahasildar Dummies (Wind Measure = Velocitypow)

Equation/ variable	Exp. signs	Sample-1	Sample-2	Sample-3	Sample-4	Sample-5
Kujangparadep	(?)	-	-	-	-	-
Mahakalpada	(?)	-	-	-	-	-
Rajnagar	(?)	-	-	-	-	-
Rajkanika	(?)	-	-	-	-	-
Patamundai	(?)					
Aul	(?)	-	-	-	-	-
Garadpur	(?)	-	-	-	-	-
Marsaghai	(?)	-	-	-	-	-
Kend-derabis	(?)	-	-	-	-	-
Velocitypow	(+)	1.71** (2.54)	2.83*** (3.60)	13.43*** (5.22)	3.04*** (3.61)	7.07*** (3.57)
Surge	(+)	13.26 (1.36)	0.23 (0.02)	-31.53** (2.03)	7.58 (0.52)	1.95 (0.13)
Dcoast	(-)	0.54 (0.58)	-1.35* (1.73)	-33.10** (2.02)	0.64 (0.69)	-12.14 *** (2.91)
Topodumy	(+)	-29.25 (0.72)	-5.61 (0.20)	-51.46 (1.05)	-13.62 (0.35)	-11.82 (0.23)
Mhabitat	(?)	20.84 *** (3.17)	10.77 * (1.85)	-16.22 (0.75)	20.96*** (3.01)	-11.90 (1.47)
Mangrove	(-)	-83.97*** (3.82)	-57.60*** (3.04)	-27.26 (0.94)	-50.09*** (3.46)	-29.88 (0.73)
Casurinadumy	(-)	-45.12 (1.19)	-9.05 (0.25)	-26.09 (0.54)	-61.12 (1.22)	40.77 (0.73)
Dmajriver	(-)	-6.26** (2.38)	-7.95 *** (2.65)	-7.31 (0.47)	-8.17*** (3.09)	3.89 (0.43)
Dminriver	(-)	-8.46*** (2.73)	-5.63 (1.59)	-25.20* (1.84)	-3.15 (0.85)	-22.01 * (1.90)
Droad	(+)	-7.29 (1.21)	0.22 (0.04)	6.13 (0.77)	-0.95 (0.15)	7.87 (0.99)
Roadumy	(-)	28.47 (1.41)	11.65 (0.51)	123.03*** (2.79)	-12.66 (0.54)	-10.42 (0.24)
Male99	(+)	0.26*** (10.10)	0.20*** (6.31)	0.19*** (6.57)	0.25 *** (6.85)	0.21*** (4.94)

Literate	(-)	-53.11 (0.56)	-93.57 (1.30)	-138.36 (0.97)	63.53 (0.64)	143.73 (1.04)
Schdulcaste	(+)	61.80 (1.26)	25.28 (0.61)	112.85 (0.55)	47.06 (1.07)	137.61 (1.27)
Cultivator	(-)	-76.48 (0.17)	-1058.92** (1.92)	-1223.40* (1.73)	-191.22 (0.27)	-1381.61** (1.92)
Aglabour	(+)	-250.07 (0.51)	-860.87 (1.53)	-1539.28* (1.84)	-29.91 (0.04)	-1010.58 (1.30)
Hhworker	(-)	-768.11 (0.62)	-1561.35 (1.49)	4652.36 (0.86)	-482.06 (0.40)	-2546.71 (0.66)
Otworker	(-)	-628.36 (1.28)	-1419.20*-** (2.65)	-2996.23*-** (3.92)	-730.00 (1.11)	-2098.77**-* (2.86)
Margworker	(+)	-54.01 (0.12)	-831.14 (1.49)	-1712.47** (2.37)	53.63 (0.08)	-531.64 (0.66)
Nonworker	(+)	-125.63 (0.28)	-882.45 (1.58)	-1483.19** (2.03)	-33.99 (0.05)	-700.92 (0.93)
Constant	(?)	-122.59 (0.26)	659.73 (1.09)	307.88 (0.41)	-473.51 (0.56)	77.96 (0.09)
		N=516,R^{2-}=0.55, F (20,495) =12.12, Pro = 0.00	N=338,R2-=0.54, F (20,317) =7.77, Pro = 0.00	N=61,R2=-0.80, F (20,40) =5.74, Pro = 0.00	N=277,R2-=0.58, F (20,256) = 7.11, Pro = 0.00	N=138,R2-=0.61, F (20,117) = 7.13, Pro = 0.00

Table 8: Weighted Least Squares Estimates (weight = Aarea) for Partially Collapsed Houses without Tahasildar Dummies (Wind measure = Velocitypow)

Equation/ variable	Exp. signs	Sample-1, N=515	Sample-2, N=337	Sample-3, N = 61	Sample-4, N = 276	Sample-5, N = 138
Kujangparadep	(?)	-	-	-	-	-
Mahakalpada	(?)	-	-	-	-	-
Rajnagar	(?)	-	-	-	-	-
Rajkanika	(?)	-	-	-	-	-
Patamundai	(?)	-	-	-	-	-
Aul	(?)	-	-	-	-	-
Garadpur	(?)	-	-	-	-	-
Marsaghai	(?)	-	-	-	-	-
Kend-derabis	(?)	-	-	-	-	-
Velocitypow	(-)	-3.15 *** (4.70)	-3.42 *** (2.91)	-1.89 (0.68)	-2.34 *** (2.82)	-5.31* (1.89)
Surge	(-)	23.07 ** (1.95)	25.83 (1.39)	10.68 (0.46)	4.07 (0.27)	8.98 (0.28)
Dcoast	(+)	0.95 (0.66)	-2.90 (1.21)	17.93 (1.08)	-5.20 *** (2.80)	17.04** (2.41)
Topodumy	(-)	2.73 (0.07)	34.16 (0.61)	93.53 ** (2.10)	-118.69 * (1.76)	105.12 (1.21)
Mhabitat	(?)	4.87 (0.78)	25.13 ** (2.25)	-53.63 ** (2.46)	29.06 *** (3.20)	21.41 (1.21)
Mangrove	(+)	59.17*** (6.47)	55.61*** (4.08)	3.06 (0.16)	26.28** (2.37)	105.29*** (4.08)
Casurinadumy	(+)	-54.89 (1.57)	-122.05** (2.15)	-21.81 (0.36)	-80.87 (1.48)	-164.91* (1.76)
Dmajriver	(+)	12.85 *** (3.18)	21.55 *** (3.75)	43.66 * (1.90)	15.98*** (4.16)	55.81*** (4.46)
Dminriver	(+)	2.53 (0.44)	7.33 (0.84)	-33.03 * (1.64)	21.77*** (3.70)	-1.08 (0.05)
Droad	(-)	-7.04 (1.55)	-3.50 (0.44)	-12.04 (1.19)	4.98 (0.81)	-21.74 * (1.63)
Roadumy	(+)	-89.16*** (2.82)	-104.60 ** (2.49)	60.12 (0.89)	-157.57***- (4.77)	-30.05 (0.40)
Male99	(+)	0.12 *** (10.21)	0.13 *** (7.11)	0.06 * (1.94)	0.25 *** (15.95)	0.03 (0.96)

Literate	(+)	286.96 (1.58)	449.64 * (1.84)	-469.47 * (1.79)	180.66 (0.81)	-133.87 (0.30)
Schdulcaste	(-)	305.37*** (3.40)	473.53 *** (3.78)	578.48** (2.49)	16.57 (0.17)	390.55 (1.40)
Cultivator	(+)	719.17 (1.28)	1083.09 (1.38)	-425.30 (0.58)	1285.96 (1.32)	-148.24 (0.13)
Aglabour	(-)	-628.57 (0.96)	-189.28 (0.20)	-2820.24 *** (3.04)	2319.69** (2.24)	-2336.63 (1.48)
Hhworker	(+)	4081.35 * (1.77)	4790.41 (1.21)	-6925.53 (0.84)	1267.60 (0.43)	11424.54 (1.15)
Otworker	(+)	351.78 (0.48)	1296.09 (1.24)	-1425.96 (1.54)	2604.23** (2.21)	24.09 (0.02)
Margworker	(-)	659.73 (1.17)	1503.89 * (1.93)	-854.09 (1.18)	2802.33*** (2.95)	-164.65 (0.14)
Nonworker	(-)	985.02 * (1.78)	1918.83 ** (2.47)	-255.43 (0.37)	2687.08*** (2.71)	394.97 (0.34)
Constant	(?)	-585.08 (1.04)	-1568.67 ** (1.98)	1095.51 (1.25)	-2297.46**- (2.27)	384.31 (0.31)
		F(20,494) =34.04,Pro- =0.00, R^2 =0.56	F(20,316) =22.24, Pro = 0.00, R^2 =0.56	F(20,40) = 8.66, Pro = 0.00, R^2 =0.72	F(20,225) =70.48, R^2 =0.83	F(20,117)=- 11.43, R^2 = 0.60

Table 9: Robust Tobit Estimates for Swept Away Houses with Tahasildar Dummies Wind measure = velocitypow)

Equation/ variable	Exp.- signs	Sample-1	Sample-2	Sample-3	xxSample-4	Sample-5
Kujangparadep	(?)	434.92*** (2.92)	65.93*** (4.17)	-180.79*** (4.31)	277.77 (1.45)	10.11 (0.40)
Mahakalpada	(?)	-35.53 (0.37)	25.18* (1.89)	-73.99*** (3.30)	75.91 ** (2.02)	-14.43 (0.79)
Rajnagar	**(?)**	**-103.04 (1.14)**	**33.34*** (4.41)**	**Dropped**	**6.78 (0.24)**	**Dropped**
Rajkanika	(?)	Dropped	Dropped	Dropped	Dropped	Dropped
Patamundai	(?)	Dropped	Dropped	Dropped	Dropped	-104.68*** (3.62)
Aul	(?)	Dropped	Dropped	Dropped	Dropped	Dropped
Garadpur	(?)	Dropped	Dropped	Dropped	Dropped	Dropped
Marsaghai	(?)	Dropped	Dropped	Dropped	Dropped	-93.79*** (4.11)
Kend-derabis	(?)	Dropped	Dropped	Dropped	Dropped	Dropped
Velocitypow	(+)	-1.58 (0.87)	-0.34 * (1.82)	1.84 *** (3.49)	-2.92 (1.35)	-0.10 (0.36)
Surge	(+)	2.78 (0.16)	0.23 (0.14)	-0.84 (0.30)	-3.96 (1.10)	-1.06 (0.60)
Dcoast	(-)	-6.80 (1.35)	0.72 (1.55)	-1.41 (0.58)	3.68 (1.52)	1.21 (1.24)
Topodumy	(+)	100.23 ** (2.50)	-1.60 (0.38)	0.99 (0.16)	-7.12 * (1.78)	7.37 (1.53)
Mhabitat	(?)	30.18*** (3.17)	-0.29 (0.26)	-6.19 ** (2.00)	10.83 (1.11)	-0.49 (0.50)
Mangrove	(-)	-7.28 (0.56)	-2.40 (1.38)	-3.93 (1.11)	-14.41 (1.31)	-3.59 (1.29)
Casurinadumy	(-)	10.84 (0.27)	10.51 * (1.68)	3.28 (0.66)	-7.21 (1.41)	10.56 * (1.92)
Dmajriver	(-)	-3.67 (0.85)	-1.61 (1.58)	1.67 (0.70)	-9.02 (1.29)	-5.56 *** (2.84)
Dminriver	(-)	12.31 (1.25)	-4.74 *** (3.14)	-4.07 (1.08)	0.01 (0.01)	-5.80 *** (2.83)
Droad	(+)	30.52*** (5.04)	0.13 (0.17)	2.69 * (1.82)	1.52 (1.36)	0.78 (0.76)

Roadumy	(-)	82.06 ** (2.02)	6.80 * (1.78)	38.90*** (2.98)	3.51 (0.93)	6.71 (1.59)
Male99	(+)	0.08*** (2.63)	0.01 * (1.85)	0.01 (1.54)	0.01 (1.18)	0.009 ** (2.13)
Literate	(-)	-417.08 * (1.91)	-40.79** (2.23)	-85.57 *** (2.75)	-44.24 * (1.68)	-45.71 ** (2.42)
Schdulcaste	(+)	-71.66 (0.63)	-18.84 (1.10)	-161.98*** (3.75)	4.34 (0.37)	-56.94 ** (2.10)
Cultivator	(-)	-221.60 (0.42)	126.56 (1.20)	56.65 (0.40)	848.94 (1.11)	177.10 (1.53)
Aglabour	(+)	-146.29 (0.19)	116.62 (1.00)	147.89 (1.05)	796.87 (1.10)	173.95 (1.41)
Hhworker	(-)	-844.40 (0.24)	926.01 * (1.85)	1451.58*** (3.02)	3167.24 ** (2.36)	1838.15*** (2.47)
Otworker	(-)	-1176.60 * (1.60)	44.99 (0.32)	173.23 (1.10)	597.84 (1.01)	149.26 (0.99)
Margworker	(+)	-31.39 (0.06)	114.29 (1.04)	276.17 (1.46)	662.76 (1.01)	191.83 (1.50)
Nonworker	(+)	-73.01 (0.12)	123.97 (1.09)	188.37 (0.96)	756.29 (1.05)	193.38 (1.45)
Constant	(?)	-7.89 (0.01)	-95.59 (0.83)	-304.85 (1.46)	-525.30 (0.97)	-151.25 (1.10)
N		N=516 (449 zero & 67 nonzero)	N=338 (309 zero & 29 nonzero)	N=61 (49 zero & 17 nonzero)	N=277 (265 zero & 12 nonzero)	N=138 (111 zero & 27 nonzero)
		Wald Chi2 (23)=85.00, Pro > Chi2=0.00	Wald Chi2 (23)=139.3-0, Pro > Chi2=0.00	Wald Chi2 (22)=195.6-1, Pro > Chi2=0.00	LR Chi2 (23) =123.03, Pro > Chi2=0.00	Wald Chi2 (24)=267.9-6, Pro > Chi2=0.00

[xx]Simple tobit estimates as every variable came out significant in robust tobit.

Table 10: Robust Poisson Estimates for Buffaloes Loss and OLS Estimates with Robust Std Errors for Cattle Loss without Tahasildar Dummies (Wind measure = velocitypow)

		Buffaloes loss			Cattle loss		
Equation/ variable	**Exp.- signs**	**Sample-1, N=68**	**Sample-2, N=41**	**Sample-2, (results without nonworker & literates)**	**Sample - 1, N= 143**	**Sample - 2, N= 89**	**Sample - 2, N= 89 (results without non-workers)**
Mahakalpada	(?)	-	-	-	-	-	-
Rajnagar	**(?)**	-	-	-	-	-	-
Rajkanika	(?)	-	-	-	-	-	-
Patamundai	(?)	-	-	-	-	-	-
Aul	(?)	-	-	-	-	-	-
Garadpur	(?)	-	-	-	-	-	-
Marsaghai	(?)	-	-	-	-	-	-
Kend-derabis	(?)	-	-	-	-	-	-
Velocitypow	(+)	0.001 (0.17)	-0.01 (0.53)	-0.007 (0.37)	2.94 ** (2.38)	2.37 (1.52)	2.27 (1.44)
Surge	(+)	-0.25** (2.03)	-0.34 (1.57)	-0.29** (1.97)	-45.84 ** (1.99)	-0.37 (0.01)	-0.62 (0.02)
Dcoast	(-)	-0.06** (2.24)	-0.03 (1.22)	-0.52 * (1.73)	-7.24 *** (3.52)	-9.42 *** (3.37)	-9.50*** (3.48)
Topodumy	(+)	0.72 ** (1.96)	1.10* (1.75)	0.96 * (1.82)	184.86 (1.52)	95.26 (0.69)	110.4 (0.78)
Mhabitat	(?)	0.16*** (3.05)	0.03 (0.23)	0.08 (1.32)	24.92 ** (2.13)	41.17 ** (2.53)	40.69** (2.51)
Mangrove	(-)	-0.37* (1.60)	-0.32 (0.79)	-0.36* (1.60)	-36.29 * (1.96)	-44.07 * (1.82)	-46.92 * (1.96)
Casurinadumy	(-)	0.16 (0.50)	0.04 (0.03)	0.43 (0.61)	-46.21 (0.84)	-15.11 (0.15)	-9.19 (0.09)
Dmajriver	(-)	-0.12* (1.93)	-0.11 * (1.60)	-0.08 (1.26)	-12.18 ** (2.03)	-15.82** (2.15)	-15.82** (2.16)
Dminriver	(-)	0.01 (0.10)	-0.19 (0.93)	-0.11 (0.60)	5.88 (0.99)	0.42 (0.04)	0.45 (0.04)
Droad	(+)	0.02 (0.29)	-0.12 (1.10)	-0.11 (0.97)	2.39 (0.39)	6.52 (0.63)	5.54 (0.54)
Roadumy	(-)	1.69*(1.83)	2.18 ** (1.96)	1.81* (1.90)	140.63 ** (2.10)	181.52 ** (1.99)	185.88** (2.06)
Buffaloes 99	(+)	0.00 (0.10)	0.00 (0.35)	0.00 (0.59)	0.02 (0.86)	0.01 (0.36)	0.01 (0.46)

Literate	(-)	1.54 (0.42)	3.42 (0.51)	ÑÑ-	-685.10 (1.58)	-288.67 (0.53)	-296.6 (0.55)
Schdulcaste	(+)	1.83 (0.93)	1.09 (0.39)	1.62 (0.81)	167.91 (0.97)	183.98 (0.81)	204.9 (0.90)
Cultivator	(+)	-8.38 (0.88)	0.98 (0.08)	14.17 (1.40)	716.62 (0.53)	511.89 (0.31)	1347.38* (1.96)
Aglabour	(+)	-3.38 (0.33)	-8.99 (0.52)	9.93 (1.09)	-1060.35 (0.70)	-1945.14 (0.99)	-983.8 (0.88)
Hhworker	(-)	-6.40 (0.22)	-2.85 (0.02)	-130.09 (1.04)	-4234.70 (1.48)	-11409.97 (1.19)	-10847.49 (1.17)
Otworker	(-)	-12.40 (0.90)	-6.82 (0.28)	19.41 (1.24)	575.01 (0.32)	694.16 (0.29)	1807.46 (1.40)
Margworker	(+)	-19.71* (1.60)	-41.77** (2.18)	-12.63*** (2.83)	-1052.76 (0.71)	-775.02 (0.43)	-189.29 (0.98)
Nonworker	(+)	-9.89 (0.89)	-25.37 * (1.72)	ÑÑ	-954.96 (0.66)	-983.68 (0.55)	ÑÑ-
Constant	(?)	11.51 (1.20)	23.49** (1.97)	2.21 (1.11)	973.80 (0.70)	815.14 (0.47)	-128.76 (0.35)
		Wald Chi2 (20)= 218.12, Pseudo R2=0.60	Wald Chi2 (20) =148.84, Pseudo R2= 0.72	Wald Chi2 (18) =148.72, Pseudo R2=0.69	F (20,122) = 7.64, R2 = 0.65	F (20, 68) = 10.07, R2 = 0.72	F (19, 69) = 10.04, R2 = 0.72

Table 11: Elasticity of Mangrove and other Variables on Different Types of Damages for the Sample 2 Area (Cyclone outer eye area with Mhabitat > 0)

Variables \ equations	Human casualties (with Tahasil dummies) N=711	Human casualties (without Tahasil dummies), N=711	Fully collapsed houses, N=338 (without Tahasil dummies)	Partially collapsed houses, N= 338 (without Tahasil dummies)	Swept away houses, N= 338, (with Tahasil dummies)[#]	Buffaloes N= 41 (without Tahasil dummies)	Cattle N=89 (without tahasil dummies)	Sheep N=89 (without tahasil dummies)
Mahakalpada	0.095	--	--	--	0.156 **	-	--	--
Rajnagar	-0.258	--	--	--	0.011***	--	--	-
Rajkanika	-3.063	--	--	--	--	--	--	--
Patamundai	-0.177	--	--	--	--	--	--	--
Aul	Dropped	--	--	--	--	--	--	--
Garadpur	Dropped	--	--	--	--	--	--	--
Marshaghai	Dropped	--	--	--	--	--	--	--
Kend-derabis	0.191	--	--	--	--	--	--	--
Bhadrakh	-0.015	--	--	--	--	--	--	--
Velocitypow	-4.025***	-0.055	2.409***	-1.163***	-0.968 **	-1.218	1.36*	1.023*
Surge	0.306***	0.149*	0.0027	0.112	0.009	-0.511	-0.0028	-0.139
Dcoast	0.091	0.318	-0.212*	-0.158	0.371*	-0.656	-1.03***	-1.202***
Topodummy	0.033	0.109***	-0.004	0.012	-0.003	0.215*	0.041	-0.064
Hmangrove	0.566***	0.461***	0.301*	0.299**	-0.027	0.133	0.789**	0.643***
Mangrove	-1.248***	-1.401***	-0.221*-**	0.217***	-0.030(--0.04**)[&]	-0.58(-.6-62*)[$]	-0.223**	-0.168**
Casurindumy	0.034	0.048	-0.008	-0.070**	0.31*	0.006	-0.009	-0.004
Dmajriver	0.246***	0.038	-0.203*-**	0.233***	-0.134*	-0.421*	-0.319***	0.067
Dminriver	-0.178*	-0.201**	-0.101*	0.049	-0.277***	-0.345	0.005	0.241**
Droad	-0.110	0.112	0.003	-0.026	0.005	-0.284	0.067	0.150
Roadumy	-0.274**	-0.164	0.052	-0.218**	0.099*	1.912*	0.687**	0.139
Population-99	0.433***	0.426***	0.789***	0.608***	0.084**	-0.095	0.107	0.135
Literate	-0.269	-0.296	-0.342	0.724*	-0.488**	2.139	-0.781	-0.751
Scheduled caste	-0.289***	-0.334***	0.029	0.242***	-0.073	0.194	0.180	0.119
Cultivator	-0.282**	-0.255***	-0.746*	0.345	0.291	0.212	0.232	0.058
Aglabour	-0.006	0.03	-0.255	-0.023	0.113	-0.358	-0.406	-0.037

Hhworker	0.042	0.042	-0.026	0.035	0.051**	-0.008	-0.154	-0.008
Otworker	-0.126	-0.131	-0.423*-**	0.187	0.044	-0.361	0.156	0.198
Margworker	0.084	0.125*	-0.426	0.389*	0.192	-3.769**	-0.269	0.214
Nonworkers	-0.200	-0.405	-3.381	3.359**	1.553	-17.168*	-2.901	1.379

[#] The elasticity is for the transformed variable, y not for the original variable y* (the latent variable).

[$] (-0.662*) is the elasticity of mangrove for the model when nonworker and literates are not used as explanatory variable (both manrworker and nonworker have high correlation = 0.88 for sample-2 in the buffaloes model).

[&] (-0.04**) is the elasticity of mangroves when flooding1 is used in place of surge in the estimating equation.

APPENDIX

Table 12: Demographic and Damage Profile of Kendrapada district

Blocks/ Tahasils	No. of Villages	% of BPL[@@]	Population Density	Human death	SA	FC	PC	Intensity of house damage (FC/PC	Buffalo lost	Cattle lost	Sheep lost	Goat lost	Poultry lost
Mahakalpada	190	51	408	188	196	20809	6678	3.12	1254 (0.53)	14767 (0.52)	3076 (0.27)	3457 (0.21)	5832 (0.08)
Rajnagar	245	66	422	46	222	6693	19000	0.35	256 (0.11)	405 (0.01)	665 (0.06)	1271 (0.08)	3291 (0.05)
Rajkanika	156	59	489	00	6	1782	21873	0.08	184 (0.08)	350 (0.01)	471 (0.04)	595 (0.04)	616 (0.01)
Patamundai	138	59	577	20	0	13382	22369	0.60	57 (0.02)	1985 (0.07)	2305 (0.20)	3466 (0.21)	7806 (0.11)
Aul	118	51	598	12	2	5765	22941	0.25	44 (0.02)	325 (0.01)	189 (0.02)	445 (0.03)	960 (0.02)
Garadpur	106	60	739	38	0	14978	4168	3.60	302 (0.13)	1417 (0.05)	446 (0.04)	1013 (0.06)	28863 (0.41)
Marshaghai	133	63	680	44	0	14701	4750	3.09	150 (0.06)	407 (0.01)	1267 (0.11)	497 (0.03)	8099 (0.12)
Kendrapada	131	42	538	35	0	37651[&&]	16949	2.22	109 (0.05)	7092 (0.25)	2979 (0.26)	4997 (0.31)	14744 (0.21)
Darabis	172	67	740	67									

Source: 1. District Statistical Handbook, Government of Orissa, Bhubaneswar; 2. Emergency Office and CDVO Office, Kendrapada, Orissa.
Note: The bracketed figures on livestock damages are the percentage of losses. @@ BPL is population below poverty line
&& Except for human casualties, other damage figures were available for Kendrapada and Derabis together

Table 13: Description and Sources of Data

Data Head	Description	Source
Damages due to super cyclone	Details of Human Casualties in each village,	Emergency Office, Kendrapada and Bhadrakh district
	Number of houses swept away (SA), fully collapsed (FC) and partially collapsed (PC) in each village or in each gram panchayats	Emergency office and Tahasildar Office of Kendrapada and only Emergency Office of the District Jagatsinghpur and Bhadrakh.
	Loss of different types of livestock (Number of dead buffaloes, cattle, sheep, goat and poultry) in different gram panchayats	Office of the Chief District Veterinary Officer (CDVO), Kendrapada
Meteorological Information	Landfall wind velocity, radius of cyclone eye, and sea elevation at different coastal points	Cyclone Warning Division, Mausam Bhawan, Government of India, New Delhi
	Track of the cyclone	National Center for Disaster Management (NCDM), Indian Institute of Public Administration, New Delhi
Geo-physical Information	Distances of different villages or gram panchayats from coastline, cyclone track, river channels, metallic roads and width of present and historical mangrove forests	DCS, Bhubaneswar
Socio-economic Information:	Total population, percentage of literates, scheduled caste, different types of workers and non-workers in different villages or in gram panchayats before cyclone	Primary Census Abstract of the State of Orissa for the year 1991 and 2001
Total population of Livestock	Total population of cattle, buffaloes, sheep, goat and poultry in different gram panchayats before the cyclone	Chief District Veterinary Officer (CDVO), Kendrapada

Table 14: Poisson Estimates for Human Casualties Model with Tahasildar Dummies (Wind Measure = Velocityexp)

Equation/ variable	ExpSi-gn	Sample-1, Area with Mhabitat>-0,	Sample-2, Area with Mhabitat>-0& velocitypow <190,	Sample-3, Mhabitat >0, velocitypow <190& dcoast 10 and	Sample-4, Mhabitat >0, velocitypow < 190, dcoast >10,	Sample -5, Storm Surge Area with Mhabitat>0 &velocitye-xp<190,
Mahakalpada	(?)	2.67** (2.02)	3.39** (2.30)	15.75 (1.37)	0.37 (0.19)	2.31*** (3.04)
Rajnagar	(?)	-0.81 (0.72)	-0.51 (0.44)	13.95 (1.39)	Dropped	Dropped
Rajkanika	(?)	-12.80 (0.05)	-15.35 (0.01)	Dropped	-14.74 (0.04)	Dropped
Patamundai	(?)	0.97 (0.76)	1.72 (1.21)	12.73 (1.13)	-0.44 (0.25)	0.94 (1.29)
Aul	(?)	Dropped	Dropped	Dropped	Dropped	Dropped
Garadpur	(?)	2.18 (1.58)	Dropped	Dropped	Dropped	Dropped
Marsaghai	(?)	2.63 * (1.87)	-2.77 (1.44)	Dropped	1.38 (0.62)	1.49 (1.06)
Kend-derabis	(?)	2.61* (1.92)	3.59** (2.33)	Dropped	1.24 (0.64)	Dropped
Bhadrakh	(?)	Dropped	Dropped	Dropped	-0.33 (0.20)	Dropped
Velocityexp	(+)	-0.11*** (4.46)	-0.13*** (4.32)	-0.04 (0.69)	-0.07 (1.44)	-0.09 *** (2.82)
Surge	(+)	0.18*** (3.24)	0.17** (2.50)	0.22 (1.36)	-0.03 (0.33)	0.11 (1.30)
Dcoast	(-)	0.006 (0.50)	0.004 (0.25)	0.45 *** (3.04)	-0.02 (1.15)	0.005 (0.19)
Topodumy	(+)	0.38* (1.68)	0.24 (1.04)	2.19 *** (3.47)	-1.52 ** (1.98)	0.53** (2.20)
Hmangrove	(?)	0.10*** (3.50)	0.13*** (3.65)	-0.43*** (3.01)	0.27 *** (4.13)	0.11*** (2.62)
Mangrove	(-)	-0.64*** (3.77)	-0.57*** (3.76)	-1.41 *** (3.45)	-0.60 *** (2.69)	-0.54*** (3.77)
Casurinadumy	(-)	0.24 (1.49)	0.35* (1.86)	-0.19 (0.37)	1.00 *** (3.70)	0.26 (1.24)

Dmajriver	(+)	0.06*** (2.67)	0.06** (2.28)	0.15 (1.23)	0.04 (1.31)	0.04 (1.00)
Dminriver	(-)	-0.07*** (2.59)	-0.07 * (1.78)	-0.14 (1.25)	-0.03 (0.64)	-0.19*** (2.69)
Droad	(+)	-0.05* (1.69)	-0.04 (0.99)	-0.005 (0.01)	0.06 (0.76)	0.03 (0.76)
Roadumy	(-)	-0.20 (1.34)	-0.37 ** (2.21)	-0.09 (0.25)	-0.11 (0.49)	-0.51*** (2.66)
Pop99	(+)	0.0004*** (9.24)	0.0005*** (9.96)	0.0006***(- 6.41)	0.0005*** (5.16)	0.0006*** (8.99)
Literate	(-)	-1.06 (1.50)	-0.13 (0.17)	-2.75 ** (2.15)	2.78 ** (2.08)	0.89 (1.05)
Schdulcaste	(+)	-0.76* (1.74)	-1.43*** (2.65)	-2.89 * (1.60)	-0.67 (0.95)	-2.45*** (3.13)
Cultivator	(-)	-0.79 (1.22)	-2.07 ** (2.18)	-2.72 (1.40)	-2.81 * (1.80)	-3.18*** (3.09)
Aglabour	(+)	-0.19 (0.28)	-0.20 (0.34)	-1.27 (0.39)	5.39 ** (2.63)	-0.79 (0.56)
Hhworker	(-)	8.23 (1.04)	13.10 (1.34)	9.40 (0.31)	9.53 (0.87)	37.85*** (3.08)
Otworker	(+)	-1.79 (1.12)	-2.87* (1.63)	-5.82 * (1.83)	-4.10 (1.33)	-4.69** (2.44)
Margworker	(+)	0.82 (1.21)	0.81 (1.11)	2.83 ** (2.18)	-0.50 (0.35)	0.99 (1.11)
Nonworker	(-)	-0.29 (1.03)	-0.22 (0.59)	0.74 (0.66)	0.38 (0.42)	0.38 (0.61)
Constant	(?)	7.01*** (4.44)	20.01*** (4.25)	-7.97 (0.001)	8.13 (1.00)	12.25** (2.52)
		N = 840, LR Chi2 (27)= 735.77 (Pro. = 0..00) Pseudo R2 = 0.39	N = 711, LR Chi2 (26)= 592.29 (Pro. = 0.00) Pseudo R2 = 0.41	N= 155, LR Chi2 (23) =319.5, Pseudo R2=0.61	LR Chi2 (26)=285.83 N=556, R2=0.34	LR Chi2 (23)= 419.40, Pro=0.00, Pseudo R2=0.42

Table 15: OLS Estimates With Robust Std. Errors for Fully Collapsed Houses with Tahasildar dummies (Wind measure = velocitypow)

Equation/ variable	Exp.signs	Sample-1	Sample-2	Sample-3	Sample-4	Sample-5
Kujangparadep	(?)	905.55*** (7.13)	568.23*** (4.33)	Dropped	115.57 (0.80)	964.26*** (4.54)
Mahakalpada	(?)	870.45*** (6.78)	466.33*** (5.96)	278.56 (1.20)	-124.53 (1.20)	984.82*** (5.95)
Rajnagar	(?)	Dropped	-528.56*** (3.67)	-629.69* (1.88)	-830.97*** (5.27)	Dropped
Rajkanika	(?)	313.82*** (2.95)	-140.32 (1.22)	Dropped	-691.49*** (5.62)	Dropped
Patamundai	(?)	753.07*** (5.55)	268.36*** (2.86)	Dropped	-298.60** (2.43)	865.41*** (4.94)
Aul	(?)	508.34*** (4.21)	Dropped	Dropped	-600.86*** (5.49)	Dropped
Garadpur	(?)	1262.27*** (8.07)	Dropped	Dropped	Dropped	Dropped
Marsaghai	(?)	1160.48*** (7.56)	569.60*** (6.34)	Dropped	Dropped	1006.40***- (6.59)
Kend-derabis	(?)	865.99*** (6.81)	435.51*** (5.89)	Dropped	-144.04 (1.35)	Dropped
Velocitypow	(+)	-1.31 ** (2.11)	-0.47 (0.73)	5.17* (1.85)	-0.56 (0.61)	3.38 (1.48)
Surge	(+)	9.87 (1.19)	-0.72 (0.09)	-11.38 (1.13)	5.35 (0.41)	1.73 (0.12)
Dcoast	(-)	-0.75 (0.61)	-0.02 (0.03)	7.70 (0.82)	-0.15 (0.15)	-10.32 * (1.74)
Topodumy	(+)	-18.65 (0.53)	-6.35 (0.29)	40.19 (1.40)	-48.16 (1.42)	-36.94 (0.95)
Mhabitat	(?)	6.90 (1.21)	-0.29 (0.07)	-36.43*** 3.04)	4.13 (0.71)	-7.06 (1.22)
Mangrove	(-)	-106.68 (1.02)	-10.23 (0.58)	-35.69* (1.66)	-14.06 (0.88)	26.57 (0.77)
Casurinadumy	(-)	-7.32 (0.23)	19.52 (0.62)	19.26 (0.55)	-9.79 (0.20)	48.84 (0.99)
Dmajriver	(-)	1.05 (0.47)	-1.06 (0.38)	-0.52 (0.05)	-0.83 (0.30)	-3.18 (0.30)
Dminriver	(-)	-0.68 (0.31)	-2.43 (0.90)	-1.57 (0.16)	-2.40 (0.75)	-13.11 (1.59)
Droad	(+)	-14.21 *** (2.87)	-3.64 (0.88)	-2.08 (0.37)	-0.20 (0.03)	2.74 (0.38)

Roadumy	(-)	12.75 (0.75)	-7.91 (0.42)	42.50 (1.27)	-9.32 (0.45)	-38.15 (0.94)
Male99	(+)	0.26*** (9.54)	0.29*** (9.48)	0.29*** (10.12)	0.28*** (6.77)	0.30*** (7.29)
Literate	(-)	4.82 (0.07)	47.64 (0.81)	-143.27 (1.07)	78.29 (1.00)	89.07 (0.82)
Schdulcaste	(+)	87.45** (1.98)	27.60 (0.80)	-20.60 (0.19)	12.67 (0.36)	60.48 (0.66)
Cultivator	(-)	-148.74 (0.38)	-100.43 (0.21)	-327.01 (0.62)	88.41 (0.15)	-410.61 (0.63)
Aglabour	(+)	-406.39 (0.98)	4.94 (0.01)	-712.71 (1.08)	333.44 (0.63)	-327.97 (0.49)
Hhworker	(-)	-1507.58 (1.12)	-311.88 (0.35)	1842.28 (0.59)	-191.19 (0.19)	-386.41 (0.12)
Otworker	(-)	-585.03 (1.56)	-451.76 (1.03)	-658.64 (1.13)	-149.25 (0.65)	-874.33 (1.39)
Margworker	(+)	-135.33 (0.35)	104.70 (0.22)	-350.99 (0.60)	366.25 (0.65)	238.01 (0.31)
Nonworker	(+)	-78.16 (0.20)	184.77 (0.39)	-235.47 (0.41)	434.43 (0.71)	181.49 (0.26)
Constant	(?)	-507.64 (1.10)	-447.65 (0.84)	-362.62 (0.66)	-141.44 (0.18)	-1314.06 (1.52)
		N=516, R2= 0.66, F(28,487) = 12.55, Pro = 0.00	N=338, R2=0.71, F(26,310) = missing,	N=61, R2=0.91, F(22,38) = 17.61, Pro=0.00	N=277, R2=0.68, F(26,249) = missing,	N=138, R2=0.73, F(24,113) = missing

Table 16: Weighted Least-Squares Estimates (weight=area) for Partially Collapsed Houses with Tahasildar dummies (Wind measure = velocitypow)

Equation/ variable	Exp. signs	Sample-1	Sample-2	Sample-3	Sample-4	Sample-5
Kujangparadep	(?)	Dropped	-417.67* (1.80)	-1338.29*** (4.91)	-503.63** (2.34)	Dropped
Mahakalpada	(?)	147.13** (2.29)	-190.65 (1.09)	-935.73*** (6.17)	-432.70*** (3.57)	150.02 (0.49)
Rajnagar	(?)	455.70*** (3.75)	43.64 (0.22)	Dropped	499.46*** (3.71)	187.64 (0.40)
Rajkanika	(?)	506.43*** (4.45)	79.91 (0.40)	Dropped	28.37 (0.24)	Dropped
Patamundai	(?)	741.60*** (8.83)	368.81** (2.11)	Dropped	95.18 (0.89)	704.17* (1.82)
Aul	(?)	670.50*** (3.90)	234.81 (0.93)	Dropped	Dropped	Dropped
Garadpur	(?)	267.56 *** (3.52)	Dropped	Dropped	Dropped	Dropped
Marsaghai	(?)	216.34*** (3.07)	Dropped	Dropped	-281.07 * (1.83)	578.37* (1.63)
Kend-derabis	(?)	37.46 (0.50)	-359.82** (2.04)	Dropped	-510.56*** (4.36)	Dropped
Velocitypow	(-)	1.32 (1.32)	-0.58 (0.38)	15.20*** (4.35)	0.80 (0.77)	-3.75 (0.91)
Surge	(-)	10.60 (0.86)	-0.53 (0.03)	-31.50* (1.70)	6.27 (0.46)	-1.37 (0.04)
Dcoast	(+)	0.22 (0.10)	2.00 (0.70)	-29.51** (2.01)	0.03 (0.02)	-0.62 (0.07)
Topodumy	(-)	44.52 (1.27)	70.21 (1.40)	1.60 (0.04)	-25.76 (0.46)	111.54 (1.31)
Mhabitat	(?)	-2.72 (0.40)	19.99 * (1.88)	-29.48* (1.70)	41.73*** (4.40)	31.74 * (1.74)
Mangrove	(+)	73.24 *** (7.73)	67.13*** (5.34)	51.57*** (3.11)	21.85** (2.11)	133.77*** (5.20)
Casurinadumy	(+)	-64.28 ** (2.10)	-159.15*** (3.14)	-140.26*** (2.87)	-163.70*** (3.52)	-184.54** (2.10)
Dmajriver	(+)	9.44 ** (2.47)	16.31 *** (2.93)	35.76** (2.13)	13.95*** (4.05)	25.99* (1.89)
Dminriver	(+)	12.03 ** (2.17)	21.86 *** (2.66)	-41.71 *** (2.78)	19.93*** (3.89)	21.63 (0.95)

Droad	(-)	-12.85 *** (3.11)	-14.17 * (1.93)	17.59** (2.00)	-2.78 (0.51)	-17.95 (1.36)
Roadumy	(+)	-18.09 (0	-1.64 (0.04)	144.72*** (2.82)	-43.98 (1.52)	3.85 (0.05)
Male99	(+)	0.03 * (1.88)	0.03 (1.38)	-0.02 (0.83)	0.12*** (6.42)	-0.007 (0.16)
Literate	(+)	-204.87 (1.21)	-311.02 (1.34)	-426.04** (2.23)	352.24 * (1.79)	-394.79 (0.93)
Schdulcaste	(-)	116.16 (1.42)	138.80 (1.21)	221.32 (1.20)	110.62 (1.29)	359.56 (1.36)
Cultivator	(+)	-382.79 (0.73)	-236.81 (0.32)	-1191.76 ** (2.17)	-307.87 (0.38)	-622.44 (0.52)
Aglabour	(-)	-1151.69 * (1.92)	-1211.22 (1.40)	-2958.68*** (4.38)	-57.** (0.07)	-3259.53 ** (2.14)
Hhworker	(+)	2196.50 (1.08)	2314.99 (0.66)	1851.51 (0.30)	-1593.07 (0.67)	9006.91 (0.96)
Otworker	(+)	-701.48 (1.06)	39.29 (0.04)	-2059.22 ** (2.68)	618.74 (0.64)	-611.27 (0.37)
Margworker	(-)	-261.06 (0.51)	-156.18 (0.21)	-1941.44 *** (3.49)	673.06 (0.84)	-1171.56 (0.98)
Nonworker	(-)	-469.27 (0.92)	-324.74 (0.43)	-1564.62 *** (2.92)	3.02 (0.00)	-538.28 (0.44)
Constant	(?)	306.66 (0.57)	670.84 (0.83)	1139.18 * (1.76)	-237.12 (0.27)	1130.80 (0.91)
		N=515, F(28,486) = 38.93, Pro=0.00, R^2=0.67	N=337, F(27,309) = 25.77, Pro = 0.00, R^2=0.67	N=61, F(22,38) = 16.72, Pro = 0.00, R^2=0.85	N=276, F(27,248) =86.32, R^2=0.89	N=138, F(24,113) =11.84, R^2=0.66

Table 17: Robust Tobit Estimates for Swept Away Houses Using Flooding1 (=surge* exp(-dcoast)) in place of Surge (Wind measure = velocitypow)

Variable	Exp. sign	Sample-1	Sample-2	Sample-3	Sample-4	Sample-5
Kujangparadep	(?)	446.23*** (2.92)	70.97 *** (4.41)	-164.17 *** (4.16)	--	15.19 (0.60)
Mahakalpada	(?)	-32.31 (0.34)	27.09** (1.98)	-72.86*** (3.28)	--	-10.86 (0.60)
Rajnagar	(?)	-97.02 (1.08)	33.72*** (4.45)	Dropped	--	Dropped
Rajkanika	(?)	Dropped	Dropped	Dropped	--	Dropped
Patamundai	(?)	Dropped	Dropped	Dropped	--	-103.27*** (3.42)
Aul	(?)	Dropped	Dropped	Dropped	--	Dropped
Garadpur	(?)	Dropped	Dropped	Dropped	--	Dropped
Marsaghai	(?)	Dropped	Dropped	Dropped	--	-91.07 *** (3.90)
Kend-derabis	(?)	Dropped	Dropped	Dropped	--	Dropped
velocitypow	(+)	-1.57 (0.97)	-0.40 ** (2.16)	1.75 *** (3.53)	--	-0.22 (0.73)
Flooding1	(+)	31.83 (0.64)	11.96** (2.19)	4.32 (0.42)	--	9.10 (1.38)
Dcoast	(-)	-6.38 (1.26)	0.76 (1.58)	-1.38 (0.56)	--	1.21 (1.22)
Topodumy	(+)	102.01** (2.56)	-1.05 (0.25)	2.21 (0.41)	--	7.40 (1.50)
Mhabitat	(?)	31.07 *** (3.31)	0.31 (0.27)	-5.70 * (1.74)	--	0.03 (0.03)
Mangrove	(-)	-8.20 (0.62)	-3.15 * (1.80)	-5.29 (1.44)	--	-4.46 * (1.61)
Casurinadumy	(-)	11.84 (0.30)	11.34 * (1.81)	4.43 (0.87)	--	11.28 ** (2.02)
Dmajriver	(-)	-3.76 (0.85)	-1.40 (1.43)	1.82 (0.75)	--	-5.01 *** (2.67)
Dminriver	(-)	12.33 (1.22)	-4.32*** (2.68)	-3.81 (1.11)	--	-5.13 ** (2.29)
Droad	(+)	30.13 *** (4.93)	-0.24 (0.30)	2.76 * (1.81)	--	0.09 (0.09)

Roadumy	(-)	86.99 ** (2.07)	9.03 ** (2.46)	46.65*** (2.90)	--	7.96 ** (1.99)
Male99	(+)	0.08 *** (2.72)	0.01* (1.94)	0.01* (1.82)	--	0.01 ** (2.23)
Literate	(-)	-405.94 * (1.81)	-31.03 (1.52)	-76.04 ** (2.04)	--	-36.79 * (1.82)
Schdulcaste	(+)	-68.56 (0.58)	-13.39 (0.79)	-166.65 *** (4.40)	--	-47.81 * (1.83)
Cultivator	(-)	-208.63 (0.39)	148.20 (1.31)	39.43 (0.28)	--	202.80 * (1.65)
Aglabour	(+)	-171.49 (0.21)	121.78 (0.99)	142.77 (1.05)	--	178.07 (1.39)
Hhworker	(-)	-754.73 (0.22)	903.41 * (1.80)	1409.59*** (3.05)	--	1734.37 ** (2.29)
Otworker	(-)	-1193.52 * (1.88)	61.92 (0.42)	159.64 (1.01)	--	165.34 (1.04)
Margworker	(+)	-39.98 (0.07)	141.11 (1.20)	305.27 * (1.64)	--	230.70 * (1.66)
Nonworker	(+)	-90.29 (0.15)	149.20 (1.22)	204.45 (1.09)	--	231.75 * (1.60)
Constant	(?)	-15.63 (0.03)	-125.06 (1.01)	-325.61 (1.55)	--	-184.59 (1.29)
		N=516 (449 zero & 67 nonzero), Wald Chi2 (23)=86.57, Pro > Chi2=0.00	N=338 (309 zero & 29 nonzero), Wald Chi2 (23) = 140.54, Pro > Chi2=0.00	N=61 (44 zero & 17 nonzero), Wald Chi2 (22)=165.4-9, Pro > Chi2=0.00	N=277 (265 zero & 12 nonzero), No result due to non-converg-ence	N=138 (111 zero & 27 nonzero), Wald Chi2 (23)=262.2-3, Pro > Chi2=0.00

FIGURES

Figure 1: The 1999 Super Cyclone hitting Kendrapada

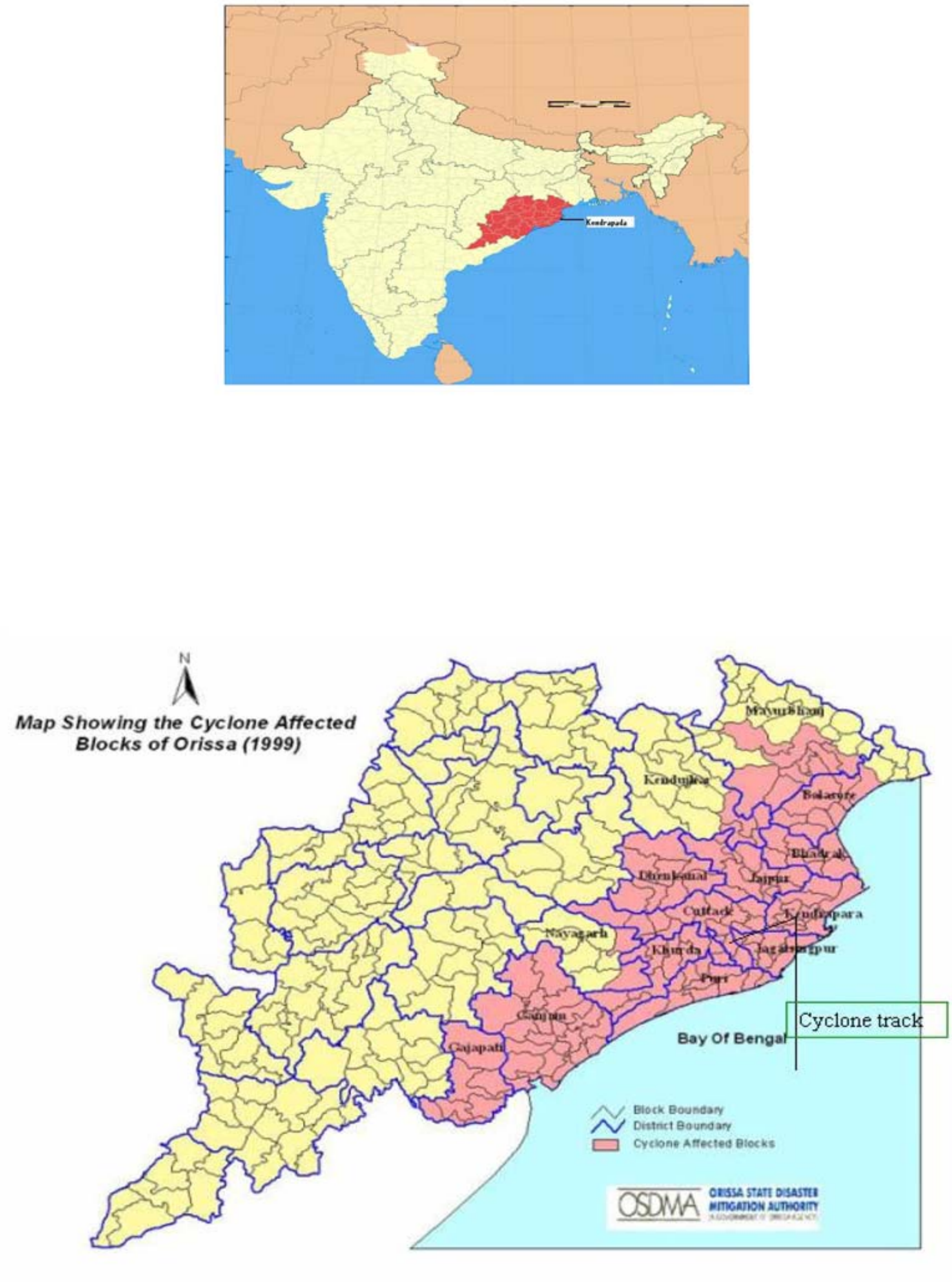

Figure 2: Mangrove Forest Cover in 1950 and the Cyclone path

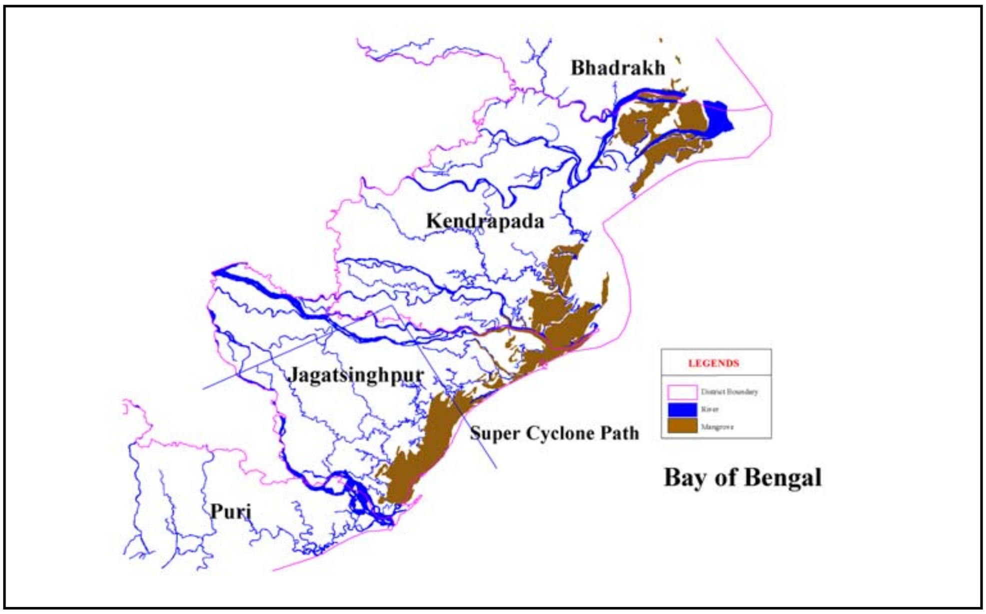

Figure 3: Mangrove Forest Cover in 1999 and the Cyclone path

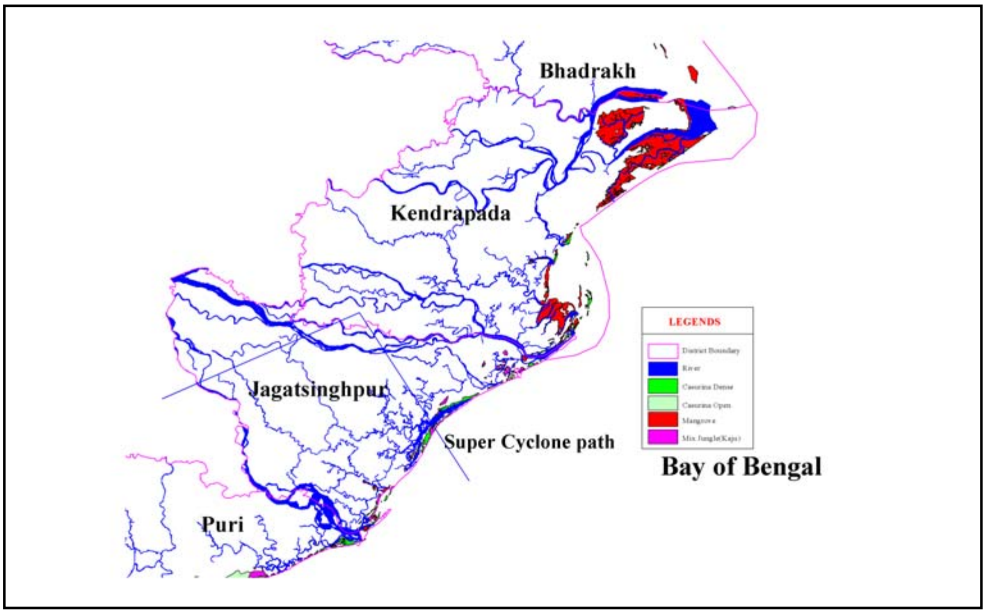

Figure 4: Sea Elevations at Orissa Coast during the Landfall of Super Cyclone 99